RISK MANAGEMENT SERIES PUBLICATION

Design Guide

for Improving School Safety in Earthquakes, Floods, and High Winds

5 Making Schools Safe From Flooding

5.1 General Design Considerations

This chapter introduces the physical nature and mechanics of floods and explains how flood probabilities are determined and how flood hazard areas are identified. It describes the types of flood damage that can result when schools are located in flood hazard areas and are affected by flooding. A series of requirements and best practices are introduced that school districts, facility planners, and designers should consider for reducing the risks from flooding to new schools and to existing school campuses that are located in floodprone areas.

This chapter demonstrates why avoidance of flood hazard areas is the most effective way to minimize the life-safety risk to students, staff, and the citizens who rely on these facilities, as well as to minimize the potential for damage to buildings and other elements of schools and campuses. When an existing school building is exposed to flooding, or a new school building is proposed to be located in a flood hazard area, steps should be taken to minimize the risks. A well-planned, designed, When new schools are being planned and constructed, and a site with a flood hazard must be used, it is important that:

- the school be placed on the portion of the site that is least vulnerable to the identified flood hazard
- the highest level of care be used for the design and construction of the school (i.e., the most stringent application of ASCE7, ASCE 24, and the local flood-plain ordinance)

constructed, and maintained school should be able to withstand damage and remain functional after a flooding event, even one of low probability. ASCE 24, *Flood Resistant Design and Construction*, provides "minimum requirements for flood-resistant design and construction of structures" (2005). Design professionals should be familiar with this standard and exercise an appropriate level of care in any construction of school buildings in flood hazard areas.

5.1.1 The Nature of Flooding

Flooding is the most common natural hazard in the United States, affecting more than 21,000 local jurisdictions and representing more than 70 percent of Presidential disaster declarations. Several studies have estimated that 7 to 10 percent of the Nation's land area is subject to flooding. Some communities have very little flood risk; others lie entirely within the floodplain.

Flooding is a natural process that may occur in a variety of forms: long-duration flooding along rivers that drain large watersheds; flash floods that send a devastating wall of water down a mountain canyon; and coastal flooding that accompanies high tides and onshore winds, hurricanes, and nor'easters. When this natural process does not affect human activity, flooding is not a problem. In fact, many species of plants and animals that live adjacent to bodies of water are adapted to a regimen of periodic flooding.

Flooding is only a problem when human development is located in areas prone to flooding. Such development exposes people to potentially life-threatening situations and makes property vulnerable to serious damage or destruction. It also can disrupt the natural surface flow, redirecting water onto lands not normally subject to flooding.

Flooding along waterways normally occurs as a result of excessive rainfall or snowmelt that exceeds the capacity of channels. Flooding along shorelines is usually a result of coastal storms that generate storm surges or waves above normal tidal fluctuations. Factors that can affect the frequency and severity of flooding and the resulting damage include:

- Channel obstructions caused by fallen trees, accumulated debris, and ice jams
- Channel obstructions caused by road and rail crossings where the bridge or culvert openings are insufficient to convey floodwaters

- Erosion of shorelines and stream banks, often with episodic collapse of large areas of land
- Deposition of sediment that settles out of floodwaters or is carried inland by wave action
- Increased upland development of impervious surfaces and manmade drainage improvements that increase rainfall-runoff volumes
- Land subsidence, which increases flood depths
- Failure of dams (resulting from seismic activity, lack of maintenance, flows that exceed the design, or destructive acts), which may suddenly and unexpectedly release large volumes of water
- Failure of levees (associated with flows that exceed the design, weakening by seismic activity, lack of maintenance, or destructive acts), which may result in sudden flooding of areas behind levees
- Failure of seawalls, revetments, bulkheads, or similar coastal structures, which can lead to rapid erosion and increased flooding and wave damage during storms

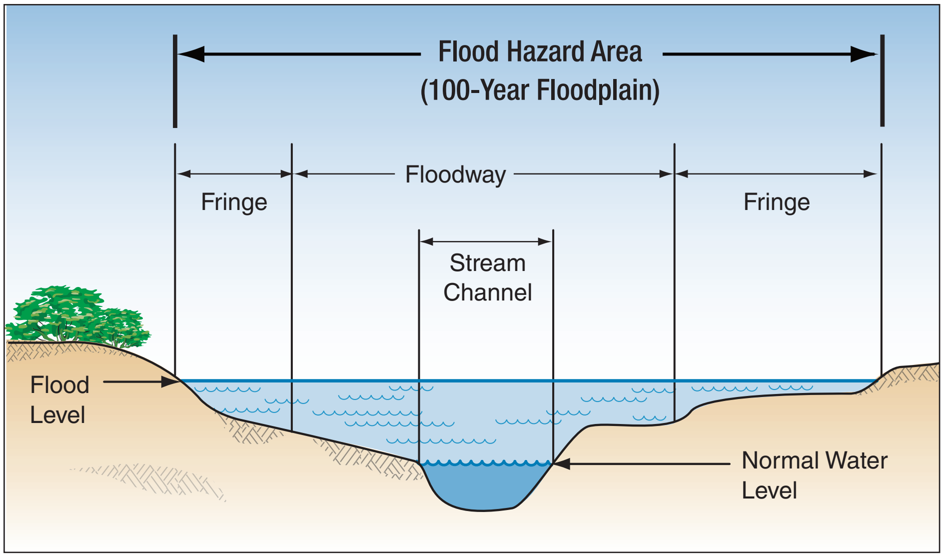
Each type of flooding has characteristics that represent important aspects of the hazard. These characteristics should be considered in the selection of school sites, the design of new school buildings and athletic facilities, and the expansion or rehabilitation of existing floodprone schools.

Riverine flooding results from the accumulation of runoff from rainfall or snowmelt, such that the volume of water exceeds the capacity of waterway channels and spreads out over the adjacent land. Riverine flooding flows downstream under the force of gravity. Its depth, duration, and velocity are functions of many factors, including watershed size and slope, degree of upstream development, soil types and nature of vegetation, topography, and characteristics of storms (or depth of snowpack and rate of melting). Figure 5-1 illustrates a cross-section of a generic riverine floodplain.

Four Examples of Schools Vulnerable to Flood Hazards

1. Two schools in Gurnee, IL, were damaged by floods in 1986. The school district's actual costs were over $1.6 million to repair and replace the facilities, supplies, and materials. Not included in this figure are the costs for transportation and rental, and disruption of the school year for children who, for several months, attended school in a vacant department store 4 miles away. For an additional 2 years of renovation and reconstruction, the children attended school in another community 8 miles away. One school was later rebuilt as a flood-protected facility for a cost of $17 million, all of which was paid by local taxpayers.
2. In April 2003, a dry floodproofed private school in Jackson, MS, was soaked when a sudden downpour dumped 9 inches of rain on the area. Because the event occurred in the pre-dawn hours when no one was on site to install the floodproofing measures (e.g., water-tight doors and special seals), water entered the building, causing damage to carpets, walls, furniture, and equipment.
3. In 1989, Hurricane Hugo vividly revealed the importance of knowing whether schools are prone to flooding. The local emergency manager's records identified the McClellanville, SC, school as an approved hurricane shelter. Unfortunately, that designation was based on the erroneous information about the elevation of the building. When storm surge flooding inundated the school, people had to break through the ceiling and lift everyone up to the attic.
4. Flooding in the spring of 2001 tested flood protection for the Oak Grove Lutheran High School in Fargo, ND (see Figure 5-29). Prompted by the failure of temporary earth and sandbag dikes during the 1997 Red River flood of record, which resulted in over $3.5 million in damage to the school, the city designed and constructed a brick-faced permanent floodwall. Five access points, wide enough for vehicles, were protected with an "invisible" closure that is an integral part of the floodwall. A crew of six installed the closures in less than 2 hours.

Figure 5-1:
The riverine floodplain



Coastal flooding is experienced along the Atlantic, Gulf, and Pacific coasts, and the Great Lakes. Coastal flooding is influenced by storm surges associated with tropical cyclonic weather systems (hurricanes, tropical storms, tropical depressions, typhoons), extratropical systems (nor'easters and other large low-pressure systems), seiches and tsunamis (surges induced by seismic activity). Coastal flooding is characterized by wind-driven waves that also may affect areas along the Great Lakes shorelines; winds blowing across the broad expanses of water generate waves that can rival those experienced along ocean shorelines. Some Great Lakes shorelines experience coastal erosion, in part because the erosion is associated with fluctuations in water levels. Figure 5-2 is a schematic of a generic coastal floodplain.

5.1.2 Probability of Occurrence or Frequency

The probability of occurrence, or frequency, is a statement of the likelihood that an event of a certain magnitude will occur in a given period of time. For many decades, floodplain management has been based on the flood that has a 1-percent chance of occurring in any given year, commonly called the "100-year flood." For certain critical actions, such as planning or constructing schools and evacuation shelters, the basis of risk decisions should be the flood that has a 0.2-percent probability of occurring in any given year, commonly called the "500-year flood." In most locations, the benefits of added protection to the 500-year level are greater than the added costs.

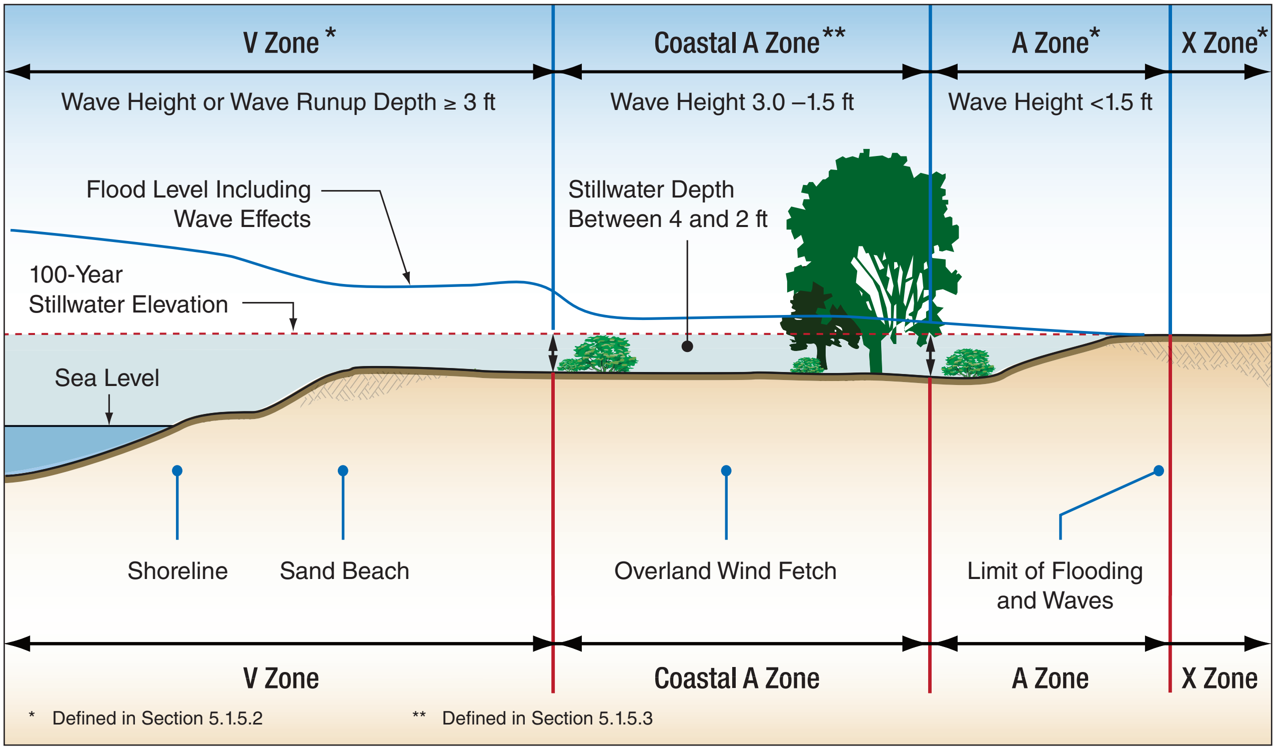


Figure 5-2: The floodplain along an open coast

The term "100-year flood" is often misunderstood because it conveys the impression that a flood of that magnitude will occur only once every 100 years. Actually, the 1-percent-annual-chance flood has one chance in 100 of occurring in any given year. The fact that a 1-percent-annual-chance flood is experienced at a specific location does not alter the probability that a flood of the same or greater magnitude could occur at the same location in the next year, or even multiple times in a single year. As the length of time considered increases, so does the probability that a flood of a specific magnitude or greater will occur. For example, Figure 5-3 illustrates that the probability a 100-year flood will occur is 26 percent during a 30-year period. And during a 70-year period (the potential useful life of many buildings), the probability increases to 50 percent. Similarly, a 500-year flood has a 0.2-percent probability of being equaled or exceeded in any given year, a 6-percent probability of occurrence during a 30-year period, and an 18-percent probability of occurrence during a 70-year period.

The assigned frequency of a flood (e.g., 100-year) is independent of the number of years between actual occurrences. Hurricane Camille hit the Mississippi coast in 1969 with storm surge flooding that far exceeded previous events, and Hurricane Katrina affected much the same area in 2005. Although just 36 years apart, both storms produced flood levels that were significantly higher than the predicted 100-year flood. Similarly, the Mississippi River flooded large areas in Missouri in 1993 with flooding that exceeded the predicted 100-year flood levels. Just 2 years later, many of the same areas were flooded again.

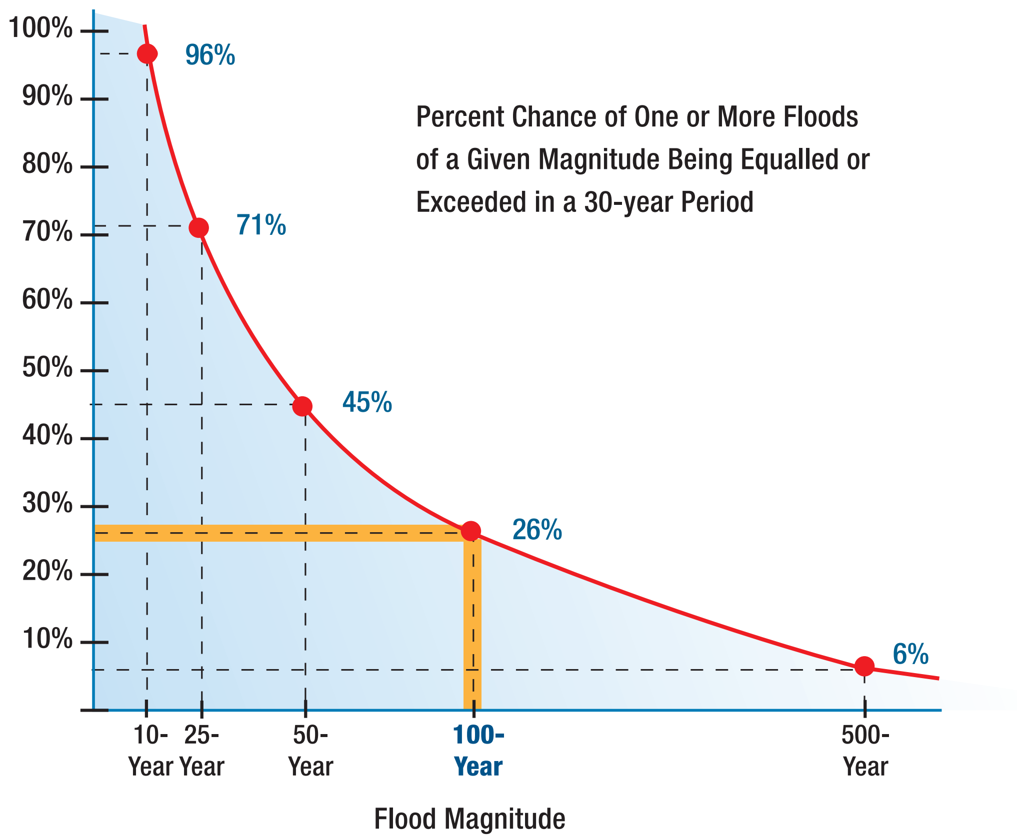


Figure 5-3: Probability and magnitude

SOURCE: U.S. GEOLOGICAL SURVEY, GUIDELINES FOR DETERMINING FLOOD FLOW FREQUENCY, BULLETIN 17B (APPENDIX D).

Regardless of the flood selected for design purposes (the “design flood”), the designer must determine specific characteristics associated with that flood. Determining a flood with a specific probability of occurrence is done in a multi-step process that typically involves using computer models available in the public domain. If a sufficiently long record of flood information exists, the design flood may be determined by applying statistical tools to the data. Alternatively, water resource engineers sometimes apply computer models to simulate different rainfall events over watersheds to predict how much water will run off and accumulate in channels. Other computer models are used to characterize the flow of water down the watershed and predict how high the floodwaters will rise.

The term “100-year flood” is often misunderstood because it conveys the impression that a flood of that magnitude will occur only once every 100 years. Actually, it has one chance in 100 of occurring in any given year.

Flood frequency analyses are performed using historical records, and the results are influenced by the length of the record. Such analyses do not account for recent changes to the land (upland development or subsidence) or future changes (additional development, greater subsidence, or climatic variations).

For coastal areas, both historical storms and simulated storm surge models can be used to predict the probability that floodwaters will rise to a certain level and be accompanied by waves of certain heights. Many coastal storms will produce storm surge flooding that, depending on local topography, may extend inland significantly farther than anticipated for a 1-percent-annual-chance flood. Other factors that influence the severity of hurricane storm surges include the forward speed of the storm, when during the tide cycle the storm comes onshore, and the near-shore bathymetry. Statistically, extreme storm surges occur less frequently than the 1-percent- or 0.2-percent-annual-chance floods, but their consequences can be catastrophic.

School facility planners and designers should research the relationship between flood levels for different frequency events, including extreme events, especially in hurricane-prone communities. The difference in flood levels may be extreme in some situations, depending on local conditions and the source of flooding. In other areas flood levels of lower probability floods might not be much higher than a 1-percent-annual-chance flood.

The National Flood Insurance Program (NFIP) is a Federal program that encourages communities to regulate flood hazard areas and, in return, offers property owners insurance protection against losses from flooding (see Sections 5.1.6.1 and 5.1.6.2). The NFIP uses the 1-percent-annual-chance flood as the basis for flood hazard maps, for setting insurance rates, and for application of regulations in order to minimize future flood damage.

The commentary of ASCE 24 provides additional information on addressing flood risk through the use of flood events other than the 1-precent-annual-chance flood, including local "flood of record" events. Nearly every year, a very low probability flood occurs somewhere in the United States, often with catastrophic consequences. Therefore, use of a lower probability flood (at least the 0.2-percent-annual-chance, or 500-year) for design purposes is strongly recommended (and may be required by some States and local jurisdictions).

> ASCE 24 sets forth that a higher level of protection is required for critical facilities, essential facilities, and schools. This higher level of protection considers additional freeboard and designing for a lower probability flood event (e.g., the 0.2-precent-annual-chance flood)."

As noted in Section 5.1.6.3, the 500-year level of protection is required if Federal funds are involved in constructing critical facilities that are vital for emergency response and rapid recovery. This reinforces the importance of protecting both the functionality and financial investment in a school by applying stricter standards than those required for other buildings. Students and the community experience significant and long-term impacts if a damaged school is closed for an extended period of time.

5.1.3 Flood Characteristics and Loads

A number of factors associated with riverine and coastal flooding are important in the selection of sites for schools, in site design, and in the determination of flood loads required as part of architectural and engineering design.

Depth: The most apparent characteristic of any flood is the depth of the water. Depending on many factors, such as the shape of a river valley or the presence of obstructing bridges, riverine flooding may rise just a few feet or tens of feet above normal levels. The depth of coastal flooding is influenced by such factors as the tidal cycle, the duration of the storm, the elevation of the land, offshore bathymetry, and the presence of waves. Depth is a critical factor in building design because the hydrostatic forces on a vertical surface (such as a foundation wall) are directly related to depth, and because costs associated with protecting buildings from flooding increase with depth. Under certain conditions, hurricanes can produce storm surge flooding that is 20 to 30 feet above mean sea level or, in extreme cases along the Gulf Coast, 35 feet or higher above mean sea level.

Duration: Duration is the measure of how long the water remains above normal levels. The duration of riverine flooding is primarily a function of watershed size and the longitudinal slope of the valley (which influences how fast water drains away). Small watersheds are more likely to be "flashy," a characteristic that refers to the rapidity with which floodwaters rise and fall. Areas adjacent to large rivers may be flooded for weeks or months. Most coastal flooding is influenced by the normal tidal cycle, as well as how fast coastal storms move through the region. Areas subject to coastal flooding can experience long periods of flooding where drainage is poor or slow as a result of topography or the presence of flood control structures. For example, water may be trapped in depressions in the land or behind a floodwall or levee with inadequate drainage. More commonly, coastal flooding is of shorter duration, on the order of 12 to 24 hours, especially if storms move rapidly. Flooding of large lakes, including those behind dams, can be of very long duration because the large volume of water takes longer to drain. For building design, duration is important because it affects access, building usability, and saturation and stability of soils and building materials. Information about flood duration is sometimes available as part of a flood study or can be developed by a qualified engineer.

Local drainage problems create ponding and local flooding that is often not directly associated with a body of water such as a creek or river. Although such flooding is relatively shallow and not characterized by high velocity flows, considerable damage may result. Areas with poor drainage frequently experience repetitive damage. Some local drainage problems are exacerbated by old or undersized drainage system infrastructure. Flooding caused by drainage problems typically occurs as sheetflow or along waterways with small drainage areas. This type of flooding is generally not mapped or regulated.

Velocity: The velocity of floodwaters ranges from extremely high (associated with flash floods or storm surge) to very low or nearly stagnant (in backwater areas and expansive floodplains). Velocity is important in site planning because of the potential for erosion. In structural design, velocity is a factor in determining the hydrodynamic loads and impact loads. Even shallow, high-velocity water can threaten the lives of pedestrians and motorists. Accurate estimates of velocities are difficult to make, although information about mean velocities may be found in some floodplain studies.

Wave action: Waves contribute to erosion and scour, and also contribute significantly to design loads on buildings. The magnitude of wave forces can be 10 to more than 100 times greater than wind and other design loads, and thus may control many design parameters. The magnitude of wave forces can be 10 to more than 100 times greater than wind and other design loads, and thus may control many design parameters. Waves must be accounted for in site planning along coastal shorelines, in flood hazard areas that are inland of open coasts, and other areas where waves occur, including areas with sufficient fetch that winds can generate waves (such as lakes and expansive riverine floodplains). Waves on top of storm surges may be as much as 50 percent higher than the stillwater depth (flood depth without waves) of the surge.

Impacts from debris and ice: Floating debris and ice contribute to the loads that must be accounted for in structural design. The methods and models used to predict and delineate flood hazard areas do not specifically incorporate the effects of debris. Thus, there are few sources to determine the potential effects of debris impact loads, other than past observations and judgment.

Erosion and scour: In coastal areas, erosion refers to the lowering of the ground surface as a result of a flood event, or the gradual recession of a shoreline as a result of long-term coastal processes. Along riverine waterways, erosion refers to undermining of channel banks, lateral movement of the channel, or cutting of new channels. Scour refers to a localized lowering of the ground surface due to the interaction of currents and/or waves with structural elements, such as pilings. Soil characteristics influence an area's susceptibility to scour. Erosion and scour may affect the stability of foundations and earthen-filled areas, and may cause extensive site damage.

5.1.3.1 Hydrostatic Loads

Hydrostatic loads occur when water comes into contact with a building or building component, both above and below the ground level. They act as lateral pressure or vertical pressure (buoyancy). Hydrostatic loads on inclined or irregular surfaces may be resolved into lateral and vertical loads based on the surface geometry and the distribution of hydrostatic pressure.

Lateral hydrostatic loads are a direct function of water depth (see Figure 5-4). These loads can cause severe deflection or displacement of buildings or building components if there is a substantial difference in water levels on opposite sides of the component (or inside and outside of the building). Hydrostatic loads are balanced on foundation elements of elevated buildings, such as piers and columns, because the element is surrounded by water. If not oriented parallel to the flow of water, shearwalls may experience hydrostatic loads due to a difference of water depth on either side of the wall. To reduce excessive pressure from standing water, floodplain management requirements in flood zones known as "A zones" call for openings in walls that enclose areas below the flood elevation (see description of continuous perimeter wall foundation in Section 5.3.4 and description of flood zones in Section 5.1.5.2).

Buoyancy force resulting from the displacement of water is also of concern, especially for dry floodproofed buildings and aboveground and underground tanks. Buoyancy force is resisted by the dead load of the building or the weight of the tank. When determining buoyancy force, the weight of occupants or other live loads (such as the contents of a tank) should not be considered. If the building or tank does not weigh enough when empty, then additional stabilizing measures need to be taken to avoid flotation. This becomes a significant consideration for designs intended to dry floodproof a building (described in Section 5.3.5). Buoyancy force is slightly larger in saltwater, because saltwater weighs slightly more than fresh water.

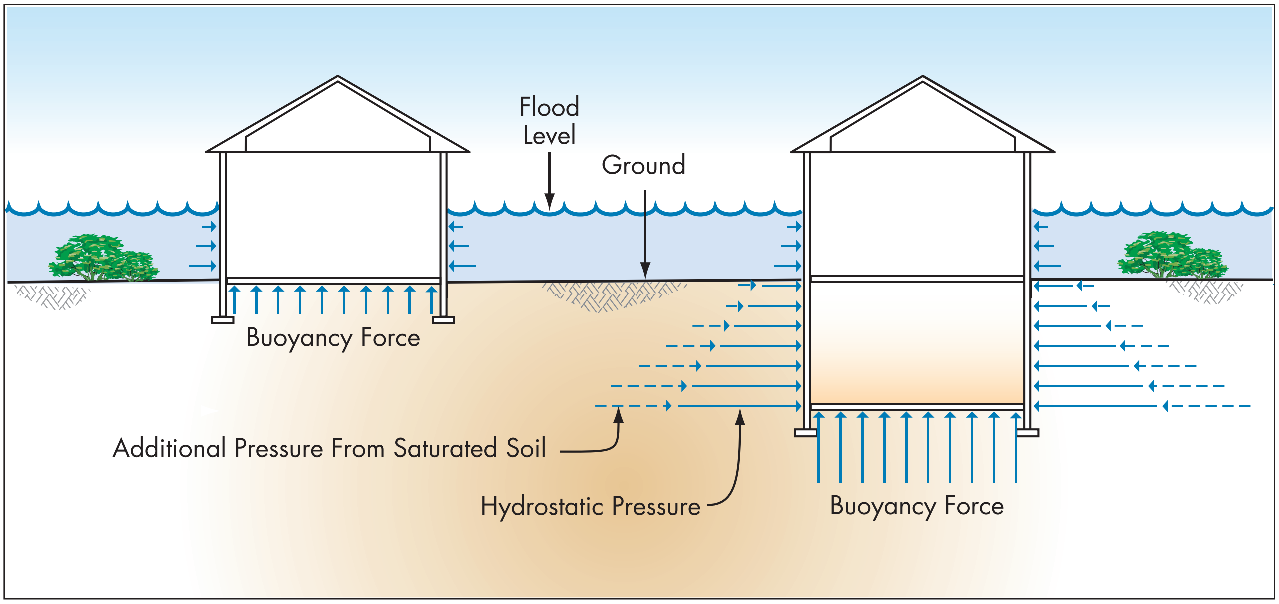


Figure 5-4: Hydrostatic loads on buildings

5.1.3.2 Hydrodynamic Loads

Water flowing around a building or a foundation structural element below the flood level imposes hydrodynamic loads. The loads, which are a function of flow velocity and structure geometry, include frontal impact on the upstream face, drag along the sides, and suction on the downstream side (see Figure 5-5). Breaking waves also impart hydrodynamic loads. Ways to determine or estimate flood velocities are described in Section 5.1.4.3 (riverine) and Section 5.1.4.4 (coastal).

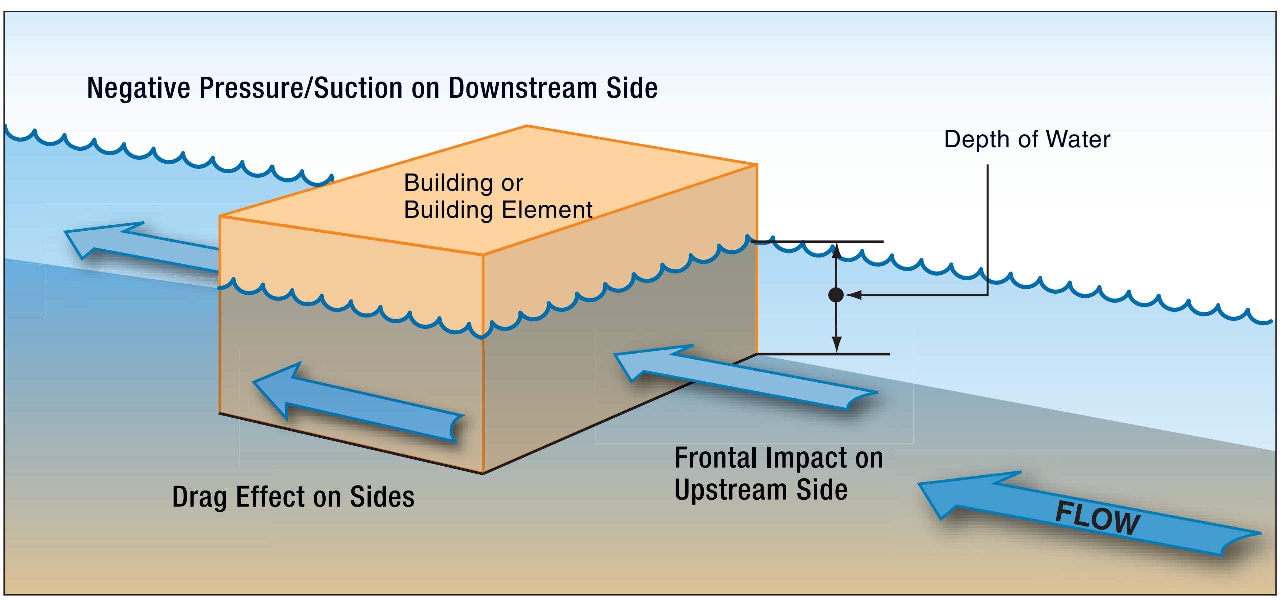


Figure 5-5: Hydrodynamic loads on a building or building element

The most common computation methods for hydrodynamic loads are outlined in the design standard ASCE 7, produced by the American Society of Civil Engineers' Structural Engineers Institute (ASCE/SEI). These methods assume that the flood velocity is constant (i.e., steady state flow) and the hydrodynamic loads are then determined according to the principles of fluid mechanics or hydraulic models. For practical applications, hydrodynamic loads become important when flow reaches moderate velocities of 5 feet per second. Drag coefficients for common building elements, such as columns and piers, can be found in a number of sources and ASCE 7 recommends values for a variety of conditions.

Wave loads are another important component of hydrodynamic loads. As described in ASCE 7, "design and construction of buildings and other structures subject to wave loads shall account for the following loads: waves breaking on any portion of the building or structure; uplift forces caused by shoaling waves beneath a building or structure, or portion thereof; wave runup striking any portion of the building or structure; wave-induced drag and inertia forces; and wave-induced scour at the base of a building or structure, or its foundation."

Wave forces striking buildings and building elements can range from 10 to more than 100 times wind or other forces. Forces of this magnitude can be substantial, even when acting over the relatively small surface area of the supporting structure of elevated buildings. Post-storm damage inspections show that breaking wave loads overwhelm virtually all wood-frame and unreinforced masonry walls below the wave crest elevation. Only engineered or massive structural elements are capable of consistently withstanding breaking wave loads.

The magnitude of wave forces provides the rationale for the floodplain management requirement that the bottom of the lowest horizontal structural member be at or above the design flood elevation (DFE) in environments where high-velocity wave action from storms or seismic sources is possible (called "V zones," also referred to as Coastal High Hazard Areas). In V zones, breaking wave heights or wave runup depths are predicted to be 3 feet or higher. Because breaking waves as small as 1.5 feet in height can impose considerable loads, there is a growing awareness of the value of accounting for waves in areas immediately landward of V zones, which are referred to as "Coastal A Zones" (see Section 5.1.5.3).

Of the variety of wave forces described in ASCE 7—breaking waves, uplift, wave runup, wave-induced drag and inertia, and scour—breaking waves constitute the greatest hazard. Designers should therefore use breaking wave forces as the basis of the design load. Computation of breaking wave loads depends on the determination of wave height.

For more information on estimating wave heights, see Section 5.1.4.1. Designers should refer to ASCE 7 for detailed discussion and computation procedures for determining breaking wave loads.

Breaking wave loads on vertical walls or supporting structural members reach a maximum when the direction of wave approach is perpendicular to the wall. It is common to assume that the direction of approach will be perpendicular to the shoreline, in which case the orientation of the wall to the shoreline will influence the direction of approach used in load calculations. ASCE 7 provides a method to reduce breaking wave loads on vertical walls when waves are expected to approach a building from a direction other than straight on.

Breaking wave forces are much higher than typical wind pressures, even wind pressures that occur during a hurricane or typhoon. However, the duration of individual loads is brief, with peak pressures probably occurring within 0.1 to 0.3 seconds after the wave breaks. Structures are to be designed for repetitive impact loads that occur over the duration of a storm. Some storms may last just a few hours, as hurricanes move through the area, or several days, as during some winter coastal storms (nor'easters) that affect the Mid-Atlantic and northeastern States.

5.1.3.3 Debris Impact Loads

Debris impact loads on a building or building element are caused by objects carried by moving water. Objects commonly carried by floodwaters include trees, trash containers, outdoor furniture, storage sheds, dislodged tanks, and remnants of manmade structures such as docks and buildings. Extreme impact loads result from less common sources, such as shipping containers, boats, and barges. The magnitude of these loads is very difficult to predict, yet some reasonable allowance for the possibility of debris impacts should be made during the design process.

Impact loads are influenced by the location of the building in the potential debris stream. The potential for debris impacts is significant if a building is located immediately adjacent to, or downstream from, other buildings, among closely spaced buildings, or downstream of large floatable objects. While these conditions may be observable in coastal areas, estimating the potential for debris is more difficult in riverine flood hazard areas. Any riverine waterway, whether a large river or smaller urban stream, can carry large quantities of debris, especially uprooted trees and trash.

The basic equation for estimating the magnitude of impact loads depends on the values of several variables, which must be determined by the designer. These variables include several coefficients, building or building element stiffness, debris weight, debris velocity, and duration of impact. The latter three variables, described in more detail in ASCE 7, are briefly described below.

Debris weight: Debris weight is one of the more difficult variables to estimate. Unless otherwise indicated by field conditions, ASCE 7 recommends using an average object weight of 1,000 pounds. This weight corresponds to a 30-foot long log that is 1 foot in diameter, which is relatively small compared to large trees that may be uprooted during a flood. In coastal areas, expected debris weights depend on the nature of the debris. In the Pacific Northwest, large trees and logs are common, with weights in excess of 4,000 pounds. In areas where piers and pilings are likely to become debris, 1,000 pounds is reasonable. In areas where most debris is likely to result from building damage (failed decks, steps, failed walls, propane tanks), the average debris weight may be less than 500 pounds.

Debris velocity: The velocity of the debris when it strikes a building depends on the nature of the debris and the velocity of floodwaters. For the impact load computation, the velocity of the waterborne object is assumed to be the same as the flood velocity. Although this assumption is reasonable for smaller objects, it is considered conservative for large objects.

Debris impact duration: Duration of impact is the elapsed time during which the impact load acts on the building or building element. The duration of impact is influenced primarily by the natural frequency[1] of the building or element, which is a function of the building's stiffness. Stiffness is determined by the properties of the material, the number of supporting members (columns or piles), the height of the building above the ground, and the height at which the element is struck. Despite all the variables that may influence duration of impact, an early approach suggested assuming a 1-second duration. A review of results from several laboratory tests that measured impacts yielded much briefer periods, and ASCE 7 currently recommends the duration of 0.03 second.

5.1.3.4 Erosion and Local Scour

Strictly speaking, erosion and scour are not loads; however, they must be considered during site evaluation and load calculations because they increase the local flood depth, which in turn influences load calculations.

Erosion may occur in riverine and coastal flood hazard areas. In coastal areas, storms can erode or completely remove sand dunes, which act as

1 Natural frequency is the frequency at which an object will vibrate freely when set in motion.

barriers to flooding and damaging waves. Erosion may also lower the ground surface or cause a short-term or long-term recession of the shoreline. In areas subject to gradual erosion of the ground surface, additional foundation embedment depth can mitigate the effects. However, where waterways are prone to changing channels and where shoreline erosion is significant, engineered solutions are unlikely to be effective. Avoidance of sites in areas subject to active erosion is usually the safest and most cost-effective course of action.

Local scour results from turbulence at the ground level around foundation elements. Scour occurs in both riverine and coastal flood hazard areas, especially in areas with erodible soils. Determining potential scour is critical in the design of foundations, to ensure that the bearing capacity or anchoring resistance of the soil around posts, piles, piers, columns, footings, or walls is not compromised. Scour determinations require knowledge of the flood depth, velocity, waves, soil characteristics, and foundation type.

At some locations, soil at or below the ground surface can be resistant to local scour, and calculated scour depths based on unconsolidated surface soils below will be excessive. If the designer believes the underlying soil at a site may be scour-resistant, a geotechnical engineer or geologist should be consulted.

5.1.4 Design Parameters

Flood hazards and characteristics of flooding must be identified to evaluate the impact of site development and to determine the design parameters necessary to calculate flood loads, to design floodproofing measures, and to identify and prioritize retrofit measures for existing schools. Table 5-3 in Section 5.6 outlines a series of questions to facilitate this objective.

5.1.4.1 Flood Depth

Flood depth is the most important factor required to compute flood loads because almost every other flood load calculation depends directly or indirectly on this factor. The first step in determining flood depth at a specific site is to identify the flood that is specified by the building code or floodplain management regulations enforced by the governing authority. The most common flood used for design is the “base flood” (see Section 5.1.4.2). ASCE 24 provides clear direction on identifying the regulatory flood. Local regulations and requirements should be compared to ASCE 24 and the most restrictive condition should be followed. The second step is to determine the expected elevation of the ground at the site. This expected ground elevation must account for any erosion, scour, subsidence, or other ground eroding condition that occurs over time. Flood depth is computed by subtracting the ground elevation from the flood elevation. Since these data are usually obtained from different sources, determining whether they are based on the same datum is important. If not, standard datum corrections must be applied.

In coastal areas, the flood elevations shown on FEMA flood maps account for stillwater flooding plus local wave effects, including wave heights, wave runup, or wave overtopping over vertical walls. As shown in Figure 5-6, subtracting the ground elevation from the FEMA flood elevation results in the flood depth which is comprised of the stillwater component and the predicted wave contribution.

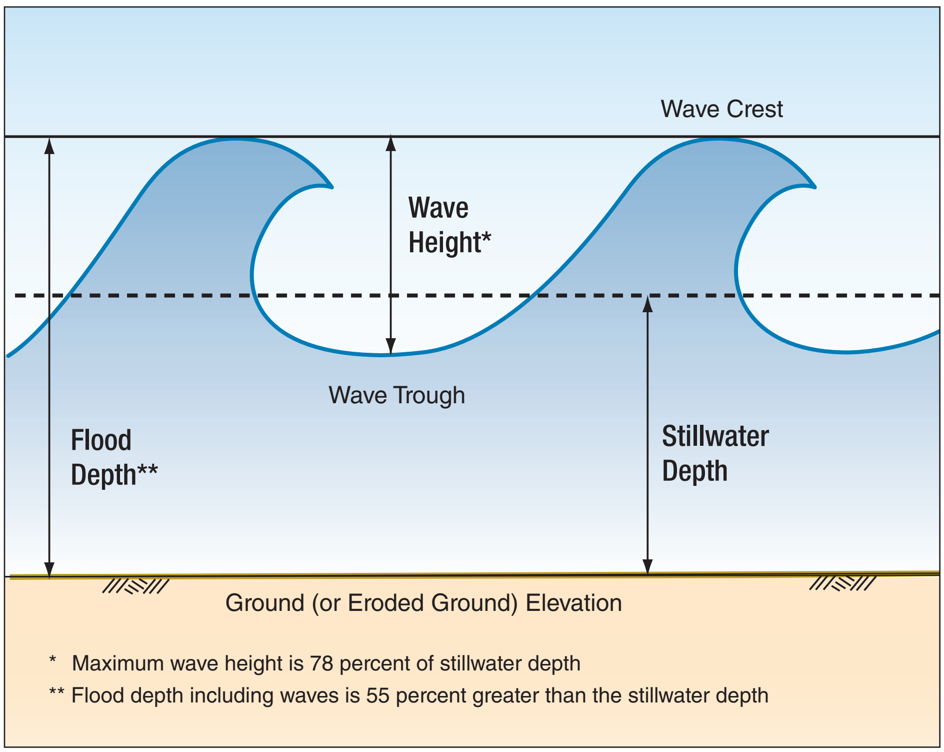


Figure 5-6: Definition sketch – coastal wave height and stillwater depth

For design purposes, it is important to know that wave forces on buildings cause the most damage. FEMA has identified V zones (velocity zones) on coastal flood maps, where wave heights or wave runup depths are predicted to be 3 feet or greater (see Section 5.1.5.2). However, post-disaster assessments and laboratory studies have shown that waves heights as small as 1.5 feet can also cause significant damage. While FEMA flood maps do not specifically designate flood hazard areas subject to 1.5- to 3-foot waves, referred to as "Coastal A Zones" (see Section 5.1.5.3), these smaller waves and their potential damaging effects on buildings should still be considered.

Figure 5-6 also illustrates the two main principles used to estimate wave heights at a particular site. Equations for wave height are based on the concept that waves are depth-limited, that is, waves propagating into shallow water will break when the wave height reaches a certain proportion of the underlying stillwater depth. For modeling wave heights during the base flood, FEMA utilizes the proportion first determined by the National Academy of Sciences (1977): the total wave height will reach a maximum of 78 percent of stillwater depth before breaking. At any given site, this proportion may be reduced because of obstructions between open water and the site, such as dense stands of vegetation or unelevated buildings. In V zones, 3-foot waves can be supported in only 4 feet of stillwater and 1.5-foot waves can be supported in only 2 feet of stillwater depth. The second principle is that the wave height extends from the trough, which is below the stillwater elevation, to the crest, which is above the stillwater elevation, and is equal to 55 percent of this stillwater depth.

Waves and storm-induced erosion are most common in coastal areas. However, wide rivers and lakes may experience wind-driven waves and erodible soils are found throughout the United States. For more information about waves and erosion, refer to FEMA 55, *Coastal Construction Manual* (2000).

Using these two principles, some general rules of thumb are available to estimate wave heights. If the only information available is the base flood depth (i.e., the flood depth calculated using the FEMA flood map elevation minus the ground elevation), assume that flood depths between 3 and 6 feet can have an added wave-height component between 1.5 and 3 feet, while flood depths of 6 feet or more will likely have wave heights in excess of 3 feet. If only the stillwater flood depth is known (from an alternative surge map or other data source), the maximum flood depth (including wave height) will be approximately 1.5 times the stillwater depth.

In any area with erodible soils, whether coastal or inland site, designers must consider the effects of erosion where floodwaters lower the ground surface or cause local scour around foundation elements. The flood depth determined using flood elevation and ground elevation should be increased to account for changes in conditions during a flood event. Not only does lowering the ground surface effectively result in deeper water against the foundation, it may also remove supporting soil from the foundation, which must be accounted for in the foundation design.

After Hurricane Katrina in 2005, FEMA expedited development of Flood Recovery Maps and Advisory Base Flood Elevations for the Mississippi coast; the new maps were delivered less than 3 months after the storm.

In 2004, after widespread wildfires in California changed rainfall-runoff characteristics, FEMA developed Flood Recovery Maps to show increased riverine flood hazards.

5.1.4.2 Design Flood Elevation

The DFE establishes the minimum level of flood protection that must be provided. For school buildings, the DFE will always be higher than the BFE. Communities may use a design flood that is higher than the base flood for a number of reasons. For example, a design flood may be used to account for future upland development, to recognize a historic flood, or to incorporate a factor of safety, known as freeboard.

School districts, facility planners, and designers should check with the appropriate regulatory authority to determine the minimum flood elevation to be used in site planning and building design. If a regulatory authority does not enforce a building code that refers to the standard *Flood Resistant Design and Construction* (ASCE 24), planners and designers should examine the provisions of that standard and discuss with decisionmakers the merits of conforming with this engineering standard of care.

"**Freeboard**" is a factor of safety usually expressed in feet above a flood level. Freeboard compensates for the many unknown factors that could contribute to flood heights, such as wave action, constricting bridge openings, and the hydrological effect of urbanization of the watershed. ASCE 24 requires that new schools with a population of 250 or more be constructed, at a minimum, to an elevation of the BFE + 2 feet in V Zones and Coastal A Zones (depending upon the orientation of the lowest floor member).

Some State or local regulations cite the 0.2-percent-annual-chance flood (500-year flood) as the design requirement for essential and critical facilities such as schools, or the regulations may call for added freeboard above the minimum flood elevation. Even if there is no specific requirement to use the 0.2-percent-annual-chance flood for siting and design purposes, FEMA strongly recommends that decisionmakers take into consideration the flood conditions associated with this lower probability event.

If significant flood events have occurred since the effective date of the FIRM, these events may change the statistical analyses, which might prompt FEMA to update of the flood maps and produce revised elevations for the 1-percent-annual-chance flood. School districts, facility planners, and designers should contact appropriate community officials to determine whether any significant flood events have occurred or if other changes that might affect flood hazards have taken place since the effective date of the FIRM. The best available information should be used at all times.

5.1.4.3 Flood Velocity—Riverine

Few sources of information are readily available for estimating flood velocities at specific locations along riverine bodies of water. If a riverine source has been studied using detailed hydraulic methods, some information may be available in summary form in published flood studies. Studies prepared for the NFIP contain tables of data for waterways for which floodways were delineated (see Section 5.1.5.2). For specified cross-sections along the waterway, these Floodway Data Tables include mean velocities expressed in feet per second. These values are the average of all velocities across the floodway. Generally, velocities in the flood fringe (landward of the floodway) will be lower than in the floodway.

For waterways without detailed studies, methods that are commonly used in civil engineering for estimating open channel flow velocities can be applied.

5.1.4.4 Flood Velocity—Coastal

Estimating flood velocities in coastal flood hazard areas involves considerable uncertainty and there is little reliable historical information or measurements from actual coastal flood events. In this context, velocity does not refer to the motion associated with breaking waves, but the speed of the mass movement of floodwater over an area.

The direction and velocity of floodwaters can vary significantly throughout a coastal flood event. Floodwaters can approach a site from one direction as a storm approaches, then shift to another direction (or through several directions) as the storm moves through the area. Floodwaters can inundate some low-lying coastal sites from both the front (e.g., ocean) and the back (e.g., bay, sound, or river). In a similar manner, at any given site, flow velocities can vary from close to zero to very high. For these reasons, when determining flood loads for building design, velocities should be estimated conservatively, and floodwaters should be assumed to approach from the most critical direction.

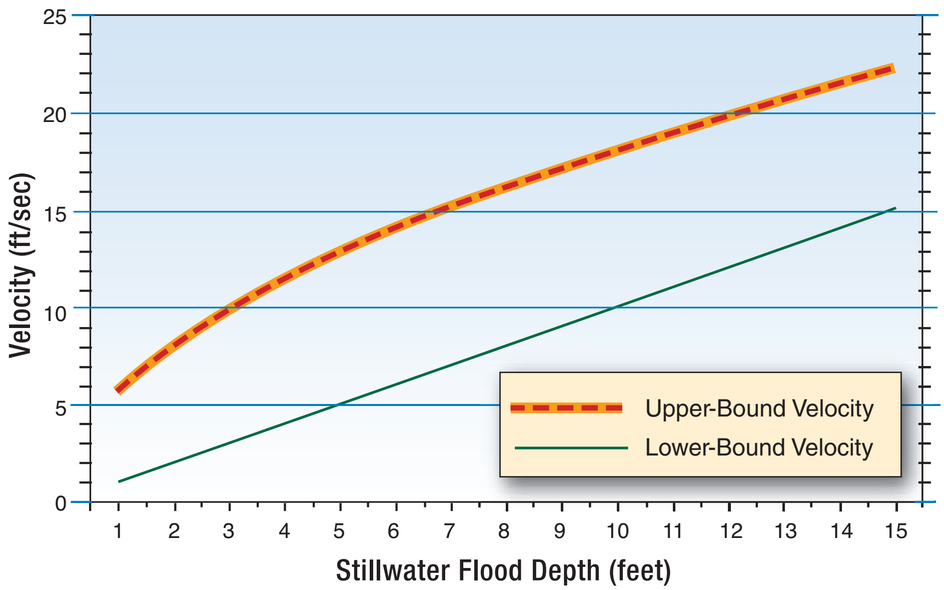
Despite the uncertainties, there are methods to approximate coastal flood velocities. One common method is based on the stillwater depth. Designers should consider the topography, the distance from the source of flooding, and the proximity to other buildings and obstructions before selecting the flood velocity for design. Those factors can direct and confine floodwaters, with a resulting acceleration of velocities. This increase in velocities is

Upper bound velocities caused by Hurricane Katrina along the Mississippi coast, where storm surge depths neared 25 feet deep (with waves, total flood depths approached 35 feet), have been estimated at nearly 30 feet per second (20 miles per hour).

described as the "expected upper bound." The "expected lower bound" velocities are experienced in areas where those factors are not expected to influence the direction and velocity of floodwaters.

Figure 5-7 shows the general relationship between velocity and stillwater depth. For design purposes, actual flood velocities are assumed to lie between the upper and lower bounds. Conservative designs will use the upper bound velocities.

Figure 5-7: Velocity as a function of stillwater flood depth



5.1.5 Flood Hazard Maps and Zones

Flood hazard maps identify areas of the landscape that are subject to flooding, usually flooding by the 1-percent-annual-chance flood. Maps prepared by the NFIP are the minimum basis of State and local floodplain regulatory programs. Some States and communities have prepared maps of a floodplain based on the assumption that the upper watershed area is fully developed according to existing zoning. Some communities base their regulations on a flood of record or a historically significant flood that exceeds the base flood shown on the NFIP maps.

The flood hazard maps used by the appropriate regulatory authority should be consulted during planning and site selection, site design, and architectural and engineering design (whether for the design of new buildings or rehabilitation of existing buildings). Regardless of the flood hazard data required for regulatory purposes, additional research should be conducted on past major floods and other factors that could lead to more severe flooding.

5.1.5.1 NFIP Flood Maps

The NFIP produces FIRMs for more than 20,000 communities nationwide. Flood Insurance Studies (FISs) and FIRMs are prepared for each local jurisdiction that has been determined to have some degree of flood risk. The current effective maps are typically avail-able for viewing in community planning or permit offices.[2] Using the most recent flood hazard map is important when deter-mining site-specific flood hazard characteristics. Although many FIRMs are more than 15 years old, often one or more panels or portions of a map panel have been revised and republished. Communities must adopt revised maps to continue participating in the NFIP.

The number of revised and updated FIRMs is increasing rapidly. During the last few years, FEMA, in partnership with many States and communities, has been implementing an initiative to modernize and update all maps that are determined to be out of date. The modernization process may involve an examination of flood experience in the period since the original flood studies were prepared, use of more detailed topographic and base maps, re-computation of flood discharges and flood heights, and re-delineation of flood hazard area boundaries.

Some FIRMs do not show the 0.2-percent-annual-chance flood hazard area (500-year floodplain), and many FIRMs do not provide detailed information about predicted flood elevations along every body of water, especially smaller streams and tributaries. Determining the 500-year flood is especially difficult when records of past flood events are limited. When existing data are insufficient, additional statistical methods and engineering analyses are necessary to determine the floodprone areas and the appropriate characteristics of flooding required for site layout and building design. If a proposed school site or existing school campus is affected by flooding, a site-specific topographic survey is critical to delineate the land that is below the flood elevation used for planning purposes. If detailed flood elevation information is not available, a floodplain study may be required to identify the important flood characteristics and data required for sound design. However, having flood hazard areas delineated on a map conveys a degree of precision that may be misleading. Flood maps have a number of limitations that should be taken into consideration, especially during site selection and building design. Some of the well-known limitations include:

- Flood hazard areas are approximations based on probabilities; the flood elevations shown and the areas delineated should not be taken as absolutes, in part because they are based on numerical approximations of the real world.
- For the most part, floodplains along smaller streams and drainage areas (less than 1 square mile) are not shown.

2 Flood maps may also be viewed at FEMA's Map Service Center at http://msc.fema.gov. For a fee, copies may be ordered online or by calling (800) 358-9616. The FIS and engineering analyses used to determine the flood hazard area may be ordered through the FEMA Web site.

In communities along the Gulf and Atlantic coasts, school districts, planners, and designers should check with emergency management offices or the U.S. Army Corps of Engineers for maps that estimate storm surge flooding from several hurricane scenarios. Local planning or engineering offices may have post-disaster advisory flood maps and documentation of past storm surge events. The FIRMs and regulatory BFEs do not reflect low probability/high magnitude flooding that may result from a hurricane making landfall at a specific location.

Be aware that most storm surge maps report stillwater flood elevations only; local wave heights or wave runup are seldom included. If necessary, local wave effects should be estimated and added to the stillwater elevation when determining flood depths for design purposes (see Section 5.1.4.1).

- Especially for older maps, the topography used to delineate the flood boundary may have had contour intervals of 5, 10, or even 20 feet, which significantly affects the precision with which the boundary is determined. The actual elevation of the ground relative to the flood elevation is more critical to consider than whether an area is shown as being in or out of the mapped flood hazard area.
- Maps are based on the data available at the time they were prepared, and, therefore, do not account for subsequent upland development that increases rainfall-runoff, which may increase flooding.
- The scale of the maps may impede precise determinations (many older maps are 1 inch = 2,000 feet).
- The land surface of the floodplain may have been altered by modifications after the maps were prepared, including fills, excavations, or levees.
- Local conditions are not reflected, especially conditions that change regularly, such as stream bank erosion and shoreline erosion.
- Areas exposed to very low probability flooding are not shown, such as flooding from extreme hurricane storm surges, extreme riverine flooding, dam failures, or overtopping or failure of levees.

5.1.5.2 NFIP Flood Zones

The flood hazard maps prepared by the NFIP show different flood zones to delineate different floodplain characteristics (see Figures 5-8, 5-9, and 5-10). The flood zones shown on the NFIP maps, and some other designations, are described below.

A Zones: Also called “unnumbered A zones” or “approximate A zones,” this designation is used for flood hazard areas where engineering studies have not been performed to develop detailed flood elevations. BFEs are not provided. Additional engineering analyses and site-specific assessments usually are required to determine the BFE.

AE Zones or A1–A30 Zones: Also called “numbered A zones,” these designations are used for flood hazard areas where engineering analyses have produced detailed BFEs and boundaries for the base flood

(1-percent-annual-chance flood). For riverine waterways with numbered A zones, FISs include longitudinal profiles showing water surface elevations for different frequency flood events.

> **Base flood elevation (BFE)** is the elevation above a datum to which floodwaters are predicted to rise during the 1-percent-annual-chance flood (also called the "base flood" or the 100-year flood).

Floodways: The floodway includes the waterway channel and adjacent land areas that must be reserved in order to convey the discharge of the base flood without cumulatively increasing the water surface elevation above a designated height. Floodways are designated for most waterways that have AE zones or numbered A zones. FISs include data on floodway widths and mean floodway velocities.

AO and AH Zones: These zones include areas of shallow flooding and are generally shown where the flood depth averages from 1 to 3 feet, where a clearly defined channel does not exist, where the path of flooding is unpredictable, and where velocity flow may be evident. These zones are characterized by ponding or sheetflow. BFEs may be provided for AH zones; flood depths may be specified in AO zones.

Shaded X (or B) Zones: These designations are used to show areas subject to inundation by the 500-year flood (0.2-percent-annual-chance flood), or areas protected by flood control levees. These zones are not shown on many NFIP maps, though the absence does not imply that flooding of this frequency will not occur.

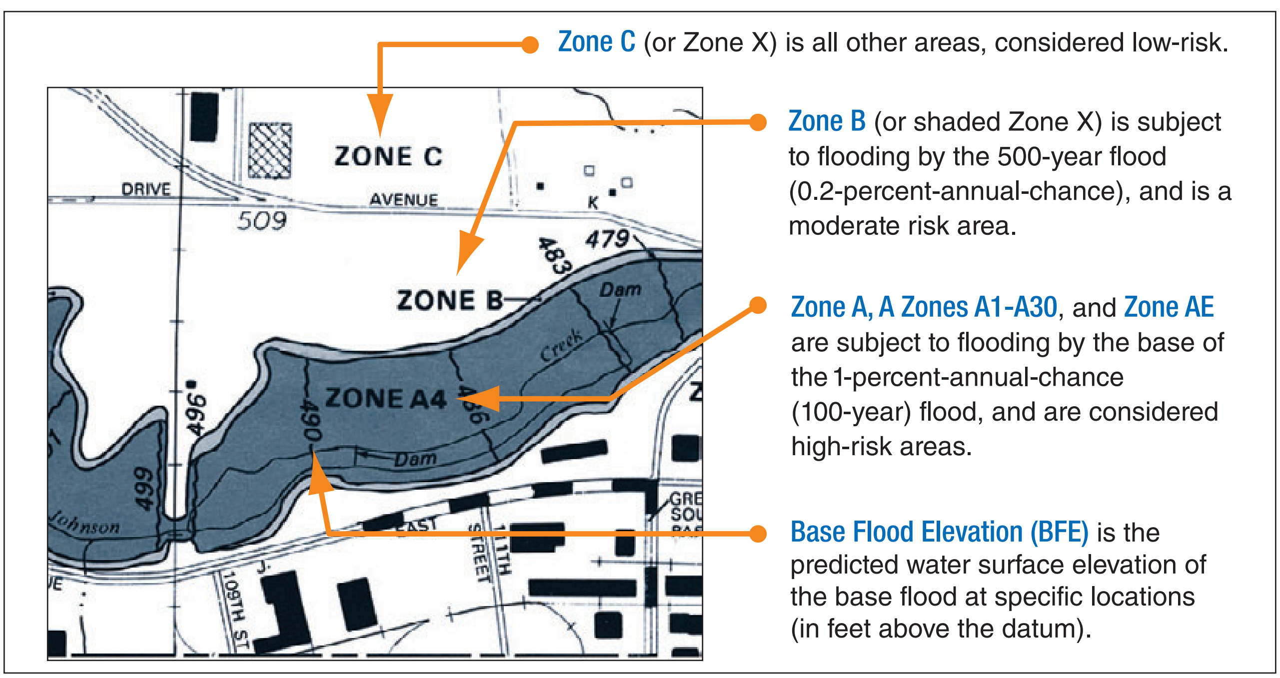


Figure 5-8: Riverine flood hazard zones

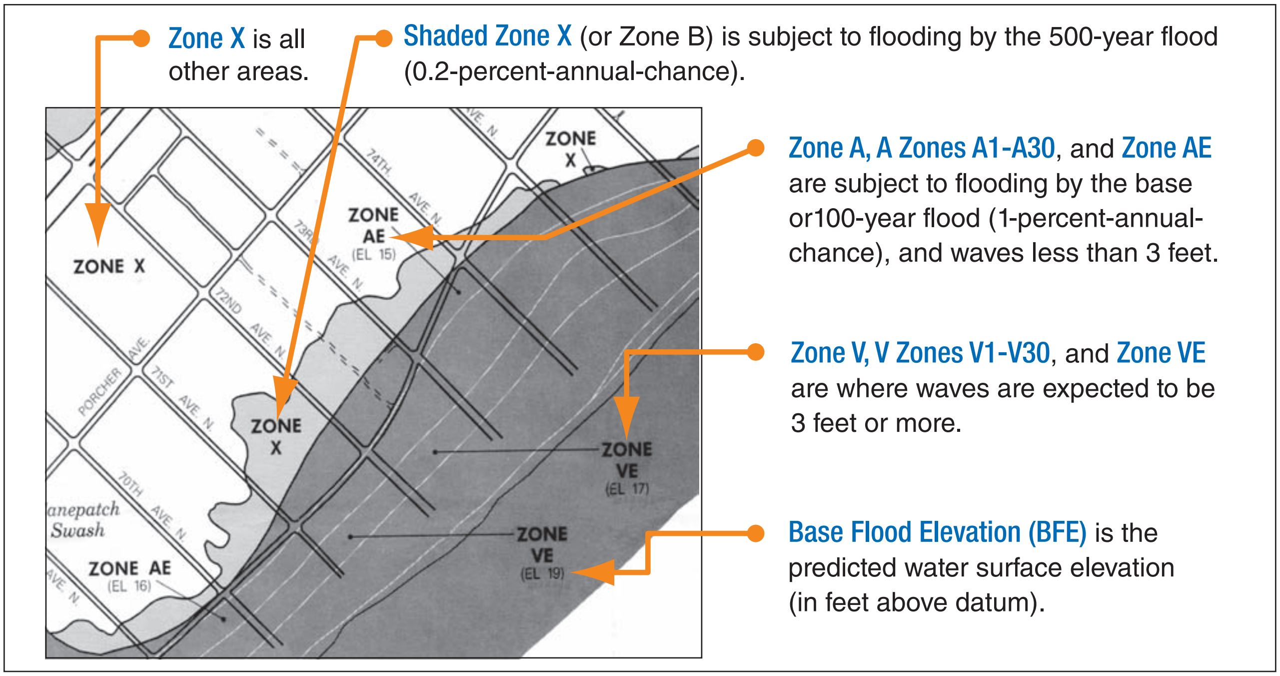


Figure 5-9: Coastal flood hazard zones

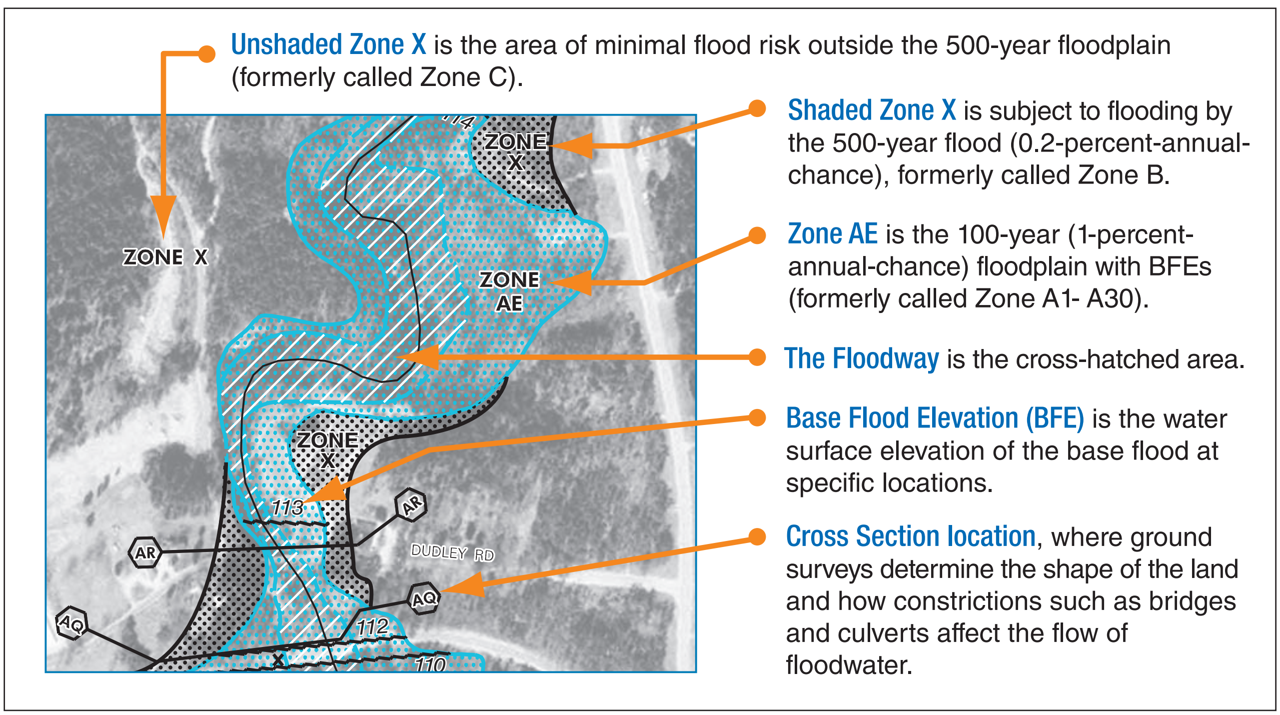


Figure 5-10: Sample digital FIRM format used for modernized maps

Unshaded X (or C) Zones: These zones are all land areas that are outside of the mapped flood hazard area designated for the purposes of regulating development. These zones may still be subject to small stream flooding and flooding from local drainage problems.

V Zones (V, VE, and V1–V30): Also known as coastal high hazard areas or special flood hazard areas (SFHAs) subject to high-velocity wave action, V zones are relatively narrow areas along open coastlines and some large lake shores that are subject to high-velocity wave action from storms or seismic sources. V zones extend from offshore to the inland limit of primary frontal dunes, or to an inland limit where the predicted breaking wave height or wave runup depth drops below 3 feet.

5.1.5.3 Coastal A Zones

Figure 5-9 shows that coastal floodplains are typically subdivided into A zones and V zones. V zones are areas where wave heights or runup depths exceed 3 feet or where primary frontal dunes occur. Most NFIP maps do not differentiate the portions of the A zone that will experience wave heights between 1.5 and 3 feet, which are capable of causing structural damage to buildings. These areas of special concern, called Coastal A Zones, can be identified through assessment of coastal flood hazard data. Beginning in 2008, when FEMA revises and updates FIRMs for coastal communities, the inland extent of the 1.5-foot wave—called the Limit of Moderate Wave Action (LiMWA)—will be delineated (Figure 5-11).

Coastal A Zones are present where two conditions exist: where the expected stillwater flood depth is sufficient to support breaking waves 1.5 to 3 feet high, and where such waves can actually occur. The first condition occurs where stillwater depths (vertical distance between the stillwater elevation and the ground) are more than 2 feet deep. The second condition occurs where there are few obstructions between the shoreline and the site. In these areas, the principal sources of flooding are tides, storm surges, seiches, or tsunamis, not riverine flooding.

The stillwater depth requirement is necessary, but is not sufficient by itself to warrant designation as a Coastal A Zone. This is because obstructions in the area may block wind (limiting the initial growth of waves) or cause friction that attenuates wave

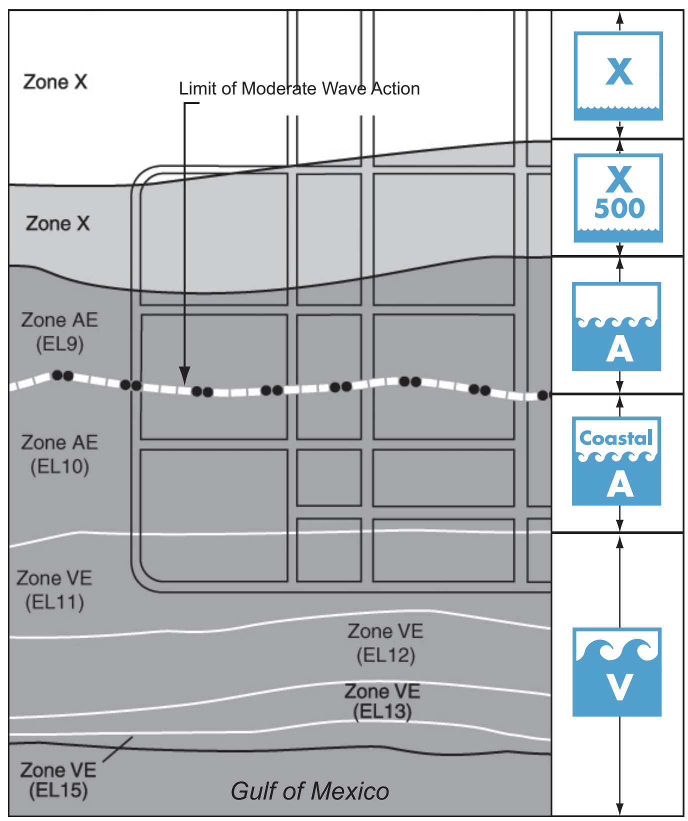


Figure 5-11:
Illustration of the Limit of Moderate Wave Action, which delineates the inland limit of areas referred to as Coastal A Zones

The current editions of the model building codes refer to two design standards, ASCE 7 and ASCE 24. Both standards include requirements for Coastal A Zones.

energy. Obstructions can include buildings, locally high ground, and dense, continuous stands of vegetation (trees, shrubs, etc.). Designers should determine whether Coastal A Zone conditions are likely to occur at a school site because of the anticipated wave action and loads. This determination is based on an examination of the site and its surroundings, the actual surveyed ground elevations, and the estimated wave heights (calculated using predicted stillwater elevations found in the FIS or derived from elevations shown on the FEMA flood map; see Section 5.1.4.1).

When a decision is made to build a school in a Coastal A Zone, the characteristics of the site and the nature of the flood hazards must be examined prior to making important design decisions. Field observations and laboratory research have determined that flooding with breaking waves between 1.5 and 3 feet high produces more damage than flooding of similar depths without waves. Therefore, ASCE 24, *Flood Resistant Design and Construction*, specifically requires application of the NFIP's V zone design requirements in Coastal A Zones. Designers are advised to pay special attention to two additional considerations:

- Debris loads may be significant in Coastal A Zones landward of V zones where damaged buildings, piers, and boardwalks can produce battering debris. Damage caused by debris can be minimized if foundations are designed to account for debris impact loads.
- Especially in high-wind regions, designers must pay special attention to the entire roof-to-foundation load path when designing and specifying connections. To meet V zone requirements, designs for buildings in Coastal A Zones should account for simultaneous wind and flood forces. Corrosion-resistant connections are especially important for the long-term integrity of the structure.

5.1.6 Floodplain Management Requirements and Building Codes

The NFIP sets the minimum requirements included in model building codes and standards for design and construction methods to resist flood damage. The original authorizing legislation for the NFIP is the National Flood Insurance Act of 1968 (42 U.S. Code [U.S.C.] 4001 et seq.). In that Act, Congress expressly found that "a program of flood insurance can promote the public interest by encouraging sound land use by minimizing exposure of property to flood losses…"

The most convincing evidence of the effectiveness of the NFIP minimum requirements is found in flood insurance claim payment statistics. Buildings that pre-date the NFIP requirements are, by and large, not constructed to resist flood damage. Buildings that post-date the NFIP (i.e., those that were constructed after a community joined the program and began applying the minimum requirements) are designed to resist flood damage. The NFIP reports that aggregate loss data indicate that buildings that meet the minimum requirements experience 70 percent less damage than buildings that pre-date the NFIP. There is ample evidence that buildings designed to exceed the minimum requirements are even less likely to sustain damage.

Construction of public schools may be regulated by a State board, school district, or State agency and, thus, may not be subject to local permit requirements, including local floodplain management regulations. In these cases, the NFIP minimum requirements must still be satisfied, whether through regulation, Executive order, or a State building code.

5.1.6.1 Overview of the NFIP

The NFIP is based on the premise that the Federal government will make flood insurance available in communities that agree to recognize and incorporate flood hazard considerations in land use and development decisions. In some States and communities, this is achieved by guiding development to areas with a lower risk. When decisions result in development within flood hazard areas, application of the criteria set forth in Title 44 Code of Federal Regulations (CFR) Section 60.3 is intended to minimize exposure and flood-related damage. State and local governments are responsible for applying the provisions of the NFIP through the regulatory permitting processes. At the Federal level, the NFIP is managed by FEMA and has three main elements:

- Hazard identification and mapping, for which engineering studies are conducted and flood maps are prepared in partnership with States and communities. These maps delineate areas that are predicted to be subject to flooding under certain conditions.
- Floodplain management criteria for development establish the minimum requirements to be applied to development within mapped flood hazard areas. The intent is to recognize and incorporate flood hazard considerations throughout the land development process.
- Flood insurance, which provides some financial protection for property owners to cover flood-related damage to buildings and contents.

Federal flood insurance is intended to shift some of the costs of flood disasters away from the taxpayer by providing property owners, including school

If completely destroyed by an event that the President declares a major disaster, schools in V zones are not eligible for post-disaster public assistance funds to rebuild on the same site (44 CFR §9.11(d)(1)). This is another reason to select higher (more conservative) design criteria when designing and constructing schools in areas with a high flood risk.

districts, an alternative to disaster assistance and disaster loans. Disaster assistance provides limited funding for repair and cleanup, and is available only after the President signs a major disaster declaration for the area. NFIP flood insurance claims are paid any time damage from a qualifying flood event[3] occurs, regardless of whether a major disaster is declared. Importantly, school districts should be aware that they may be subject to a mandated reduction in Federal disaster assistance payments if a public school building is damaged by flooding, but is not covered by flood insurance. The same restriction applies to private non-profit schools that are otherwise eligible for Federal disaster assistance.

Another important objective of the NFIP is to break the cycle of flood damage. Many buildings have been flooded, repaired or rebuilt, and flooded again. Before the NFIP, in some parts of the country this cycle was repeated every couple of years, with reconstruction taking place in the same floodprone areas, using the same construction techniques that did not adequately resist flood damage. NFIP provisions guide development to lower-risk areas by requiring compliance with performance measures to minimize exposure of new buildings and buildings that undergo major renovation or expansion (called "substantial improvement" or repair of "substantial damage"). This achieves the long-term objective of building disaster-resistant communities.

"**Substantial damage**" is damage of any origin sustained by a structure whereby the cost of restoring the structure to its before-damage condition would equal or exceed 50 percent of the market value of the structure before the damage occurred.

"**Substantial improvement**" is any repair, reconstruction, rehabilitation, addition, or improvement of a building, the cost of which equals or exceeds 50 percent of the market value of the building before the improvement or repair is started (certain historic structures may be excluded).

5.1.6.2 Summary of the NFIP Minimum Requirements

The performance requirements of the NFIP are set forth in 44 CFR Part 60. The requirements apply to all development, which the NFIP broadly defines to include buildings and structures, site work, roads and bridges, and other activities. Buildings must be designed and constructed to resist flood damage, which is primarily achieved through elevation (or floodproofing). Additional specific requirements apply to existing development, especially existing buildings. Existing buildings that are proposed for substantial improvement, including restoration following substantial damage, are subject to the regulations.

3 For the purpose of adjusting claims for flood damage, the NFIP defines a flood as "a general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or of two or more properties (at least one of which is the policyholder's property) from: overflow of inland or tidal waters; unusual and rapid accumulation or runoff of surface waters from any source; mudflow; or collapse or subsidence of land along the shore of a lake or similar body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels that result in a flood as defined above."

Although the NFIP regulations primarily focus on how to build structures, one of the long-term objectives of the program is to guide development to less hazardous locations. Preparing flood hazard maps and making the information available to the public is fundamental in satisfying this objective. Armed with flood hazard information, people can make informed decisions about where to build, how to use site design to minimize exposure to flooding, and how to design buildings that will resist flood damage.

The NFIP's broad performance standards for development sites in flood hazard areas include the following requirements:

- Building sites shall be reasonably safe from flooding.
- Adequate site drainage shall be provided to reduce exposure to flooding.
- New and replacement sanitary sewage systems shall be designed to minimize or eliminate infiltration of floodwaters into the systems and discharges from the systems into floodwaters.
- Development in floodways shall be prohibited, unless engineering analyses show that the development will not increase flood levels.

The NFIP's broad performance standards for new buildings proposed for flood hazard areas (and substantial improvement of existing floodprone buildings) include the following requirements:

- Buildings shall be designed and adequately anchored to prevent flotation, collapse, or lateral movement resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy.
- Building materials used below the DFE shall be resistant to flood damage.
- Buildings shall be constructed by methods and practices that minimize flood damage (primarily by elevating to or above the DFE, or by specially designed and certified floodproofing measures).
- Buildings shall be constructed with electrical, heating, ventilation, plumbing, and air-conditioning equipment and other service facilities that are designed and/or located to prevent water from entering or accumulating within the components.

The IBC and ASCE 24 contain several requirements that exceed or are more specific than the NFIP minimum requirements. The most notable is the requirement that schools and certain other buildings and structures be elevated to the higher of the DFE or the BFE plus 1 or 2 feet.

School planners and designers should determine whether there are any applicable State-specific requirements for floodplain development.

Some States require that local jurisdictions apply standards that exceed the minimum requirements of the NFIP. In particular, some States require that schools be located outside of the floodplain (including the 500-year floodplain). Some states require that schools are designed and constructed to resist conditions associated with the 500-year flood or other higher standards, and some States have direct permitting authority over public school construction.

As participants in the NFIP, States are required to ensure that development activities that are not subject to local regulations, such as the development of State-owned properties, comply with the same performance requirements as those enforced by local jurisdictions. If schools are exempt from local permits, this may be accomplished through a State building permit, a governor's executive order, or other mechanisms that apply to entities not subject to local authorities.

5.1.6.3 Executive Order 11988 and Critical Facilities

When Federal funding is provided for the planning, design, and construction of new critical facilities, or for the repair of existing critical facilities that are located within the 500-year floodplain, the funding agency is required to address additional considerations. Executive Order 11988, Floodplain Management, requires Federal agencies to apply a decisionmaking process to avoid, to the extent possible, the long- and short-term adverse impacts associated with the occupancy and modification of floodplains, and to avoid the direct or indirect support of floodplain development whenever there is a practicable alternative. If there is no practicable alternative, the Federal agency must take steps to minimize any adverse impacts to life, property, and the natural and beneficial functions of floodplains.

The Executive order establishes the BFE as the minimum flood elevation that must be used by all Federal agencies. Implementation guidance specifically addresses "critical actions," which are described as those actions for which even a slight chance of flooding would be too great. The construction or repair of critical facilities, such as schools, hospitals and clinics, fire stations, emergency operations centers, and facilities for storage of hazardous wastes or storage of critical records, are examples of critical actions.

After determining that a site is in a mapped flood hazard area, and after giving public notice, the

States often use governors' executive orders to influence State-constructed and State-funded critical facilities, requiring location outside of the 500-year floodplain where feasible, or protection to the 500-year flood level if avoiding the floodplain is not practical. In 2004, a review of State and local floodplain management programs determined that Alabama, Illinois, Michigan, New York, North Carolina, Ohio, and Virginia have requirements for critical facilities (ASFPM, 2004). Although not identified in that review, other States may have similar restrictions.

Federal funding agency is required to identify and evaluate practicable alternatives to locating a critical facility in a 500-year floodplain. If the Federal agency has determined that the only practicable alternative is to proceed, then the impacts of the proposed action must be identified. If the identified impacts are harmful to people, property, and the natural and beneficial functions of the floodplain, the Federal agency is required to minimize the adverse effects on the floodplain and the funded activity.

FEMA's eight-step decisionmaking process for complying with Executive Order 11988 must be applied before Federal disaster assistance is used to repair, rehabilitate, or reconstruct damaged existing critical facilities in the 500-year floodplain.

Having identified the impacts of the proposed action and the methods to minimize these impacts, the Federal agency is required to re-evaluate the proposed action. The re-evaluation must consider whether the action is still feasible, whether the action can be modified to relocate the facility or eliminate or reduce identified impacts, or whether a "no action" alternative should be chosen. If the finding results in a determination that there is no practicable alternative to locating a critical facility in the floodplain, or otherwise affecting the floodplain, then a statement of findings and a public explanation must be provided.

5.1.6.4 Model Building Codes and Standards

The IBC and NFPA 5000 were the first model codes to include comprehensive provisions that address flood hazards. Both codes are consistent with the minimum provisions of the NFIP that pertain to the design and construction of buildings and structures. The NFIP requirements that pertain to site development, floodways, coastal setback lines, erosion-prone areas, and other environmental constraints are found in other local ordinances.

ASCE 7 outlines methods to determine design loads and load combinations in flood hazard areas, including hydrostatic loads, hydrodynamic loads, wave loads, and debris impact loads. In order to compute the loads and load combinations the designer must identify site-specific characteristics, including flood depths, velocities, waves, and the likelihood that debris impacts need to be considered.

ASCE 24 addresses design and construction requirements for structures in flood hazard areas, including coastal high-hazard areas (V Zones), "Coastal A Zones," and other flood hazard areas (A Zones).

The IBC and NFPA 5000 incorporate by reference a number of standards that are developed through a formal or accredited consensus process. The best known is ASCE 7. The model building codes require designers to identify and design for anticipated environmental loads and load combinations including wind, seismic, snow and flood loads, as well as the soil conditions. The designer must identify the pertinent, site-specific characteristics and then use ASCE 7 to determine the specific loads and load combinations. In effect, the process is similar to a local floodplain ordinance that requires determination of the environmental condition (in/out of the mapped flood hazard area, DFE/depth of water), and then specifies certain conditions that must be met during design and construction. The 1998 edition of ASCE 7 was the first version of the standard to include flood loads explicitly, including hydrostatic loads, hydrodynamic loads (velocity and waves), and debris impact loads.

The IBC and NFPA 5000 also incorporate ASCE 24 by reference. ASCE 24 is a standard that was first published by ASCE in 1998 and revised in 2005. Developed through a consensus process, ASCE 24 addresses specific topics pertinent to designing and constructing buildings in flood hazard areas, including floodways, coastal high-hazard areas, and other high-risk flood hazard areas, such as alluvial fans, flash flood areas, mudslide areas, erosion-prone areas, and high-velocity areas.

Prior to the 2010 edition, ASCE 7 and the model building codes classified structures into four categories based on use or occupancy, each with different requirements, and schools were classified based on capacity. The 2010 edition of ASCE 7 categorizes buildings and structures into “risk categories” and no longer includes lists of specific facilities under each category. Schools are expected to be designated as Risk Category III or Risk Category IV in ASCE 7-10:

- **Risk Category III –** Buildings and structures the failure of which could pose a substantial risk to human life and those not included in Risk Category IV with “potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure.”
- **Risk Category IV –** Buildings and structures designated as essential facilities, and those for which failure could pose a substantial hazard to the community. Essential facilities are defined as those “intended to remain operational in the event of extreme environmental loading from wind, snow, or earthquakes.”

ASCE 24 incorporates the ASCE 7 building classifications (occupancy categories) and establishes elevation requirements for each risk category. Table 5-1 summarizes these elevation requirements, which exceed the NFIP minimum requirements for schools.

Table 5-1: ASCE/SEI 24 provisions related to the elevation of schools

	Occupancy Category III	Occupancy Category IV
Elevation of Lowest Floor or Bottom of Lowest Horizontal Structural Member		
A Zone: elevation of lowest floor	BFE + 1 foot or DFE, whichever is higher	BFE + 2 feet or DFE, whichever is higher
V Zone and Coastal A Zone: where the lowest horizontal structural member is parallel to direction of wave approach	BFE + 1 foot or DFE, whichever is higher	BFE + 1 foot or DFE, whichever is higher
V Zone and Coastal A Zone: where the lowest horizontal structural member is perpendicular to direction of wave approach	BFE + 2 feet or DFE, whichever is higher	BFE + 2 feet or DFE, whichever is higher
Elevation Below which Flood Damage-Resistant Materials Shall be Used		
A Zone	BFE + 1 foot or DFE, whichever is higher	BFE + 2 feet or DFE, whichever is higher
V Zone and Coastal A Zone: where the lowest horizontal structural member is parallel to direction of wave approach	BFE + 2 feet or DFE, whichever is higher	BFE + 2 feet or DFE, whichever is higher
V Zone and Coastal A Zone: where the lowest horizontal structural member is perpendicular to direction of wave approach	BFE + 3 feet or DFE, whichever is higher	BFE + 3 feet or DFE, whichever is higher
Minimum Elevation of Utilities and Equipment		
A Zone	BFE + 1 foot or DFE, whichever is higher	BFE + 2 feet or DFE, whichever is higher
V Zone and Coastal A Zone: where the lowest horizontal structural member is parallel to direction of wave approach	BFE + 2 feet or DFE, whichever is higher	BFE + 2 feet or DFE, whichever is higher
V Zone and Coastal A Zone: where the lowest horizontal structural member is perpendicular to direction of wave approach	BFE + 3 feet or DFE, whichever is higher	BFE + 3 feet or DFE, whichever is higher
Dry Floodproofing		
A Zone: elevation to which dry floodproofing extends	BFE + 1 foot or DFE, whichever is higher	BFE + 2 feet or DFE, whichever is higher
V Zone and Coastal A Zone: dry floodproofing not allowed	Not allowed	Not allowed

5.2 Schools Exposed to Flooding

5.2.1 Identifying Flood Hazards at School Sites

School districts, facility planners, and designers of schools and school campuses should investigate site-specific flood hazards and characteristics as part of site selection to understand the risks of locating new buildings and other improvements on a site. Where practical, buildings and athletic fields should be located outside of known flood hazard areas. The best available information should be examined, including flood hazard maps, records of historical flooding, storm surge maps, and advice from local experts and others who can evaluate flood risks. Table 5-3 in Section 5.6 outlines questions that should be answered prior to initiating site layout and design work.

This same investigation should be undertaken when examining existing schools and when planning improvements or rehabilitation work.

5.2.2 Vulnerability: What Flooding Can Do to Existing Schools

Existing schools that are located in flood hazard areas are exposed to flood damage. The nature and severity of damage are functions of site-specific flood characteristics. As described below, damage may include: site damage; structural and nonstructural building damage; destruction or impairment of service equipment; loss of contents; and health and safety threats due to contaminated floodwater.

Regardless of the nature and severity of damage, flooded schools are typically not functional while cleanup and repairs are undertaken. The length of closure, and thus the impact on the ability of the school district to provide instruction, depends on the severity of the damage and lingering health hazards. It may also depend on whether the building was fully insured or whether disaster assistance is made available quickly to allow speedy repairs and reconstruction. Sometimes, repairs are put on hold pending a determination of whether a school should be rebuilt on the same site. When damage is substantial, rehabilitation or reconstruction is allowed only if full compliance with flood-resistant design requirements is achieved (see Section 5.1.6.2).

5.2.2.1 Site Damage

The degree of site damage associated with flooding is a function of several variables related to the characteristics of the flood, as well as the site itself.

Erosion and scour: All parts of a school site that are subject to flooding by fast-moving water could experience erosion, and local scour could occur around any permanent obstructions to flow. Graded areas, filled areas, and cut or fill slopes are especially susceptible. Stream and channel bank erosion, and erosion of coastal shorelines, are natural phenomena that may, over time, threaten site improvements and buildings.

Debris and sediment: Even when buildings are not subject to water damage, floods can deposit large quantities of debris and sediment that can damage a site and be expensive to remove, especially from athletic fields.

Landscaping: Grass, trees, and plants suffer after floods, especially long-duration flooding that prevents oxygen uptake, and coastal flooding that stresses plants that are not salt-tolerant. Fast-moving floodwaters and waves can also uproot plants and trees.

Fences: Some types of fences that are relatively solid can significantly restrict the free flow of floodwaters and trap floating debris. Fences can be damaged or knocked down by the pressure of flowing water, or by the buildup of debris, which can result in significant loads.

Damage to other site elements, such as water supply, sewer lines, underground and aboveground tanks, and emergency power generators, is discussed in Section 5.2.2.5.

Playing field surfaces: In addition to damage by erosion and scour, graded grass fields and applied track surfaces can be damaged by standing water and deposited sediments.

Accessory structures: Accessory structures, such as storage sheds, bleachers, restrooms, and refreshment stands, can sustain both structural and nonstructural damage. Such structures may be designed and built using techniques that minimize damage potential, without requiring elevation above the DFE.

Access roads: Access roads that extend across floodprone areas can be damaged by erosion, washout of drainage culverts, failure of fill and bedding materials, and loss of road surface (see Figure 5-12). Road damage could prevent uninterrupted access to a school and thus impair its functionality.

Figure 5-12:
Flooding caused the failure of this road bed

SOURCE: U.S. ARMY CORPS OF ENGINEERS

Parking lots: Paved parking lots can be damaged by failure of bedding materials and loss of driving surface.

Stormwater management facilities and site drainage: Site improvements such as swales and stormwater basins can be eroded, filled with sediments, or clogged by debris.

Vehicles: If left in floodprone areas, vehicles may not be functional and available for service immediately after a flood, and must be replaced or cleaned to be serviceable (see Figure 5-13).

Figure 5-13: School bus washed away by storm surge

5.2.2.2 Structural Damage

Structural damage includes all damage to the load-bearing portions of a building. Local drainage systems around school buildings may be inadequate to handle high volume runoff from large expanses of pavement, sometimes resulting in water entering the buildings. Damage to other components of buildings is described below, including nonstructural components (Section 5.2.2.3), utility system equipment (Section 5.2.2.4), and contents (Section 5.2.2.5).

Depth: The hydrostatic load against a wall or foundation is directly related to the depth of water. Standard studs and siding, or unreinforced brick veneer walls, may collapse under hydrostatic loads associated with relatively shallow water. Reinforced masonry walls perform better than unreinforced masonry walls (see Figure 5-14); however, an engineering analysis is required to determine performance. Walls and floors of below-grade areas (basements) are particularly susceptible to damage by buoyancy forces. When soils are saturated, pressures against below-grade

Figure 5-14:
Interior unreinforced masonry walls of the Port Sulphur High School in Louisiana were damaged by hydrostatic loads associated with Hurricane Katrina's storm surge (2005)

walls are a function of the total depth of water, including the depth below-grade, and the weight of the saturated soils.

Buoyancy and uplift: If below-grade areas are essentially watertight, buoyancy or uplift forces can float a building out of the ground or rupture concrete slabs-on-grade (see Figure 5-15). Buildings that are not adequately anchored can also be floated or pushed off foundations. Although rare for large and heavy school buildings, this is a concern for outbuildings and portable (temporary) classrooms. Buoyancy is a significant concern for underground and aboveground tanks, especially those used for emergency generator fuel.

Duration: By itself, saturation is unlikely to result in significant structural damage to masonry construction, although water infiltration through the masonry walls is likely even during short periods of inundation. Saturation of soils, a consequence of long-duration flooding, increases pressure on below-grade foundation walls.

Figure 5-15: Concrete slab ruptured by hydrostatic pressure (buoyancy) induced by the floodwaters of Hurricane Katrina (2005)

Velocity, wave action, and debris impacts: Each of these components of dynamic loads can result in structural damage if buildings are not designed to resist overturning, repetitive pounding by waves, or short-duration impact loads generated by floating debris.

Erosion and scour: Structural damage is associated with foundation failure when erosion or scour results in partial or complete removal of supporting soil (see Figure 5-16). Erosion of slopes, especially unprotected slopes, can lead to slope failures and loss of soils required to support foundations.

Figure 5-16: Scour undermined the foundation of St. Paul Catholic School, Pass Christian, LA.

5.2.2.3 Nonstructural Damage

Many floodprone buildings are exposed to floodwaters that are not fast moving, or that may be relatively shallow and not result in structural damage. Simple inundation and saturation of the building and finish materials can result in significant and costly damage, including long-term health complications associated with mold. Floodwaters often are contaminated with chemicals, petroleum products, and sewage. Under such circumstances, recovery generally involves removal of nonstructural materials and finishes because cleanup and decontamination are expensive and time-consuming. Damage to contents is described in Section 5.2.2.5.

EPA's *Mold Remediation in Schools and Commercial Buildings* (2001) offers guidelines for the remediation/cleanup of mold and moisture problems in schools and include measures designed to protect the health of building occupants and remediators. Designed primarily for use by school managers and custodians, it provides a basis for making judgments as to whether the remediation should be handled in-house. The guidance outlines mold remediation plans, whether developed by school personnel or by outside contractors.

Saturation damage can vary as a function of the duration of exposure. Some materials are not recoverable even after very brief inundation, while others remain serviceable if in contact with water for only a few hours. Use of water-resistant materials will help to minimize saturation damage and reduce the costs of cleanup and restoration to service. (For more information, see FEMA NFIP Technical Bulletin 2, *Flood Damage-Resistant Materials Requirements* [2008].)

Wall finishes: Painted concrete and concrete masonry walls usually resist water damage, provided the paint used can be readily cleaned. Tiled walls may resist water damage depending on the type of adhesive and foundation (gypsum board substrate and wood-framed walls with tile do not typically remain stable).

Flooring: Most schools have durable floors that resist water damage. Ground floors are often slab-on-grade and finished with tile or sheet products. Flooring adhesives that have been in use since the early 1990s are often latex-based and tend to break down when saturated (see Figure 5-17). Most carpeting, even the indoor-outdoor kind, is difficult to clean. Wood floors are particularly susceptible to saturation damage. Short duration inundation may not cause permanent deformation of some wood floors, such as may be present in older buildings. However, because of low tolerance for surface variations, gymnasium floors are particularly sensitive and tend to warp after flooding of any duration.

Figure 5-17:
This parquet wood gymnasium floor was damaged by dimensional changes due to saturation (Hurricane Katrina 2005)

Wall and wood components: When soaked for long periods of time, some materials change composition or shape. Most types of wood swell when wet and, if dried too quickly, will crack, split, or warp. Plywood can delaminate and wood door and window frames may swell and become unstable. Gypsum wallboard, wood composition panels, other wall materials, and wood cabinetry not intended for wet locations can fall apart. The longer these materials are wet, the more moisture, sediment, and pollutants they absorb and the more likely that mold growth will develop. Some materials, such as the paper facing on gypsum wallboard, "wick" standing water, resulting in damage above the high-water line (see Figure 5-18).

Metal components: Metal structural components are unlikely to be permanently damaged by short-term inundation. However, hollow metal partitions are particularly susceptible when in contact with water because they cannot be thoroughly dried and cleaned. Depending on the degree of corrosion protection on the metal, repetitive flooding by saline coastal waters may contribute to long-term corrosion.

Figure 5-18: Saturation damage extends above the water line in this grade school in Gurnee, IL.

Metal connectors and fasteners: Depending on the composition of the metal, repetitive flooding, especially by saline coastal waters, may contribute to long-term corrosion. Connectors and fasteners are integral to the structural stability of buildings; therefore, failure caused by accelerated corrosion would jeopardize the building.

5.2.2.4 Utility System Damage

Utility system service equipment that is exposed to flooding is vulnerable to damage. Damage may result in a total loss, or may require substantial cleaning and restoration efforts. The degree of damage varies somewhat as a function of the characteristics of flooding. Certain types of equipment and installation measures will help minimize damage and reduce the costs of cleanup and restoration to service.

Equipment and appliances: Installation below the flood level exposes equipment and appliances to flood forces, including drag resulting from flowing water and buoyancy. Gas-fired appliances are particularly dangerous. flotation can separate appliances from gas sources, resulting in fires and explosive situations. Displaced equipment may dislodge lines from fuel oil tanks, contributing to the threat of fire and causing water pollution and environmental damage.

Elevators: If located in areas subject to flooding, elevator components, equipment, and controls will be damaged, and movement between floors will be impaired.

Metal components: Corrosion of metal components, whether from inundation or salt aerosols in coastal areas, may not be apparent immediately but can increase maintenance demand and shorten the useful life of some equipment and appliances.

Electrical systems and components: Electrical systems and components, and electrical controls of heating, ventilation, and air-conditioning systems, are subject to damage simply by getting wet, even for short durations. Unless specifically designed for wet locations, switches and other electrical components can short out due to deposits of sediment, or otherwise not function, even when allowed to dry before operation. Wiring and components that have been submerged may be functional, though it is generally more cost-effective to discard flooded outlets, switches, and other less-expensive components than to attempt a thorough cleaning.

Communications infrastructure: Critical communications infrastructure, such as control panels and wiring for warning systems, 911 systems, and regular telephone and wireless networks, are most susceptible to failure during emergencies if located in below-grade basements.

Ductwork: Ductwork is subject to two flood-related problems. Flood forces can displace ductwork, and saturated insulation can overload the ductwork support straps, causing failure.

Mold and dust: Furnaces, air handlers, and ductwork that have been submerged must be thoroughly cleaned and sanitized. Otherwise, damp conditions contribute to the growth of mold and accumulated sediment can be circulated throughout the school, causing respiratory problems. Fiberglass batt or cellulose insulation that has been submerged cannot be sanitized and must be replaced. In sensitive environments, ductwork should be replaced rather than cleaned.

Gas-fired systems: Waterborne sediment can impair safe functioning of jets and controls in gas-fired furnaces and water heaters, necessitating professional cleaning and inspection prior to restoration of service. Control equipment (valves, electrical switches, relays, temperature sensors, circuit breakers, and fuses) that has been submerged may pose an explosion and fire hazard and should be replaced.

Emergency power generators: Generators installed at-grade are susceptible to inundation and will be out of service after a flood (see Figure 5-19). Even if fuel tanks are located above flood level, truck access for refueling would be impaired if the site is flooded for any length of time.

Figure 5-19: Although it was anchored and not displaced by floodwaters, this generator was out of service after being submerged (Hurricane Katrina, 2005)

Tanks (underground): Underground storage tanks are subjected to significant buoyant forces and can be displaced, especially when long-duration flooding occurs and the surrounding soils become saturated.

Tanks (aboveground): Permanently installed aboveground storage tanks are subject to buoyant forces and displacement caused by moving water. Standard strapping of propane tanks may be inadequate for the anticipated loads.

Public utility service: Damage to public utility service (potable water supply and wastewater collection) can affect operations and may cause damage to schools:

- Potable water supply systems may become contaminated if distribution lines or treatment facilities are damaged, or if wellheads are submerged.
- During heavy rains, sewers back up from infiltration and inflow of stormwater into the sewer lines and manholes, cross connections between storm and sanitary sewers, and flooded wastewater treatment plants. Sewer backup into a school poses a major health hazard. Even when the water has receded, exposed building components, finish materials, and contents are contaminated, and usually must be removed because adequate cleaning is difficult, if not impossible.

5.2.2.5 Contents Damage

Schools contain equipment and contents that can be damaged and unrecoverable when exposed to flooding. For the purpose of this description, the term "contents" includes items such as furniture, kitchen goods and equipment, computers, laboratory equipment and materials, records, and library materials. The following types of contents are often total losses after flooding.

Furniture: Porous woods become saturated and swollen, and joints may separate. Generally, furniture with coverings or pads cannot be restored. Metal furniture is difficult to thoroughly dry and clean, is subject to corrosion, and is typically discarded. Depending on the type of wood, some wood furniture may be recoverable after brief inundation.

Computers: Flood-damaged computers and peripheral equipment cannot be restored after inundation (see Figure 5-20), but special recovery procedures may be able to recover information on hard drives.

Figure 5-20: Destroyed computers and peripheral equipment, Nichols Elementary School, Biloxi, MS

School records: When offices are located in floodprone spaces, valuable school records may be lost. Although expensive, some recovery of computerized and paper records may be possible with special procedures.

Library books and collections: Recovery of library materials and special collections that are saturated by floodwaters is generally difficult and expensive.

Laboratory materials and equipment: Depending on the nature of laboratory materials, cleanup may require special procedures. Generally, equipment is difficult to restore to safe functioning.

Kitchen goods and equipment: Stainless steel equipment and surfaces generally have cleanable surfaces that can be disinfected and restored to service. Because of contamination, all food stuffs and perishables must be discarded.

5.3 Requirements and Best Practices in Flood Hazard Areas

5.3.1 Evaluating Risk and Avoiding Flood Hazards

Flood hazards are very site-specific. When a flood hazard map is prepared, lines drawn on the map appear to define the hazard area precisely. Land that is on one side of the line is "in" the mapped flood hazard area, while the other side of the line is "out." Although the delineation may be an approximation, having hazard areas shown on a map facilitates avoiding such areas to the maximum extent practical. If those areas are unavoidable, school districts should carefully evaluate all of the benefits and all of the costs in order to determine long-term acceptable risks, and to develop appropriate plans for design and construction of new schools.

When a decision is made to build a new school on a site that is affected by flooding, the characteristics of the site and the nature of flooding must be examined prior to making several design decisions. The most important consideration is location of the buildings.

Risks and certain costs associated with flood-resistant construction are minimized by putting principal buildings on the highest available ground. Siting decisions for buildings, parking lots, and athletic fields should consider all site constraints, which may include the presence of flood hazard areas (see Table 5-3 in Section 5.6), wetlands, poor soils, steep slopes, sensitive habitats, mature tree stands, and other environmental factors as required by all applicable regulatory authorities. It should be possible to avoid siting new schools in riverine floodways and coastal areas subject to significant waves (V zones).

Section 5.2 describes the damage sustained by existing buildings exposed to flood hazards. Physical damage and loss of function are avoided if schools are located away from flood hazard areas.

Schools should not be located in V zones if alternate locations are available. Because of the effects of waves and potential for erosion and scour, construction in V zones must meet certain design and construction requirements that are different from those required in A zones. This section identifies these differences.

Flood hazard areas designated as V zones on FIRMs are relatively narrow areas along open coasts and lake shores where the base flood conditions are expected to produce 3-foot or higher waves. V zones, sometimes called coastal high hazard areas or SFHAs subject to high-velocity wave action, are found on the Pacific, Gulf, and Atlantic coasts, and around the Great Lakes. Every effort should be made to locate schools outside of V zones, because the destructive nature of waves makes it difficult to design a building to be fully functional during and after a flood event. This is particularly true in coastal areas subject to hurricane surge flooding.

5.3.2 Benefits and Costs: Determining Acceptable Risk

Many decisions made with respect to schools are, in part, based on a determination of acceptable risk. Risk includes the potential losses associated with a hazard. Ideally, risks can be defined in terms of expected probability and frequency of the hazard occurring, the people and property exposed, and the potential consequences.

Choosing a site or accepting donated land that is affected by flooding is a decision to accept some degree of risk. Although the floodprone land may have a lower initial cost, the incremental costs of construction, plus the likely increased costs of maintenance, repair, and replacement, may be significant. Another cost of locating a school in a floodprone area is related to access problems if streets and access roads are impassable. The building may be elevated and protected, but if access is restricted periodically, then the use of the school is affected.

Extreme hurricane storm surge flooding may be a very low-probability event, but the flood depths and wave heights may be much more severe than the conditions of the base flood shown on the FIRMs. The potential impacts on a school must be carefully considered in order to make an informed decision regarding acceptable risk and potential damage. If possible, areas subject to extreme storm surge flooding should be avoided when locating schools.

In communities with expansive flood hazard areas, there may be no practical alternatives to using a floodprone site. In these situations, an evaluation of acceptable risk should lead to selection of design measures that exceed the minimum requirements to mitigate the impacts of flooding.

The school district's planning team and the design team can influence the degree of risk (e.g., the frequency and severity of flooding that may affect the site). They control it through the selection of the site design and the building design measures. Fundamentally, this process is a balancing of the benefits of an acceptable level of disaster resistance with the costs of achieving that degree of protection. With respect to mitigation of future hazard events:

- Benefits are characterized and measured as future damage avoided if mitigation measures (including avoiding flood hazard areas) are implemented.
- Costs are the costs associated with implementing measures to eliminate or reduce exposure to hazards.

Benefits other than avoided physical damage are difficult to measure. They are associated with future damage that does not occur because of the mitigation activity, cleanup that is not required because of the mitigation activity, and continued education of children because flooding does not shut down a school. In addition, benefits accrue over long periods of time, making it difficult to make a direct comparison of the benefits with the up-front costs of mitigation. Mitigation costs can be more readily expressed in terms of the higher costs of a flood-free site, or the initial capital costs of work designed to resist flood damage. Thus, without full accounting of both benefits and costs, decisionmakers may not be able to make fully informed decisions. Some questions that should be answered include:

- If the site is floodprone and the building is out of the flood hazard area or is elevated on fill, what are the average annual cleanup costs associated with removal of sand, mud, and debris deposited by floods of varying frequencies?
- If the school is elevated by means other than fill, will periodic inundation of the exposed foundation elements cause higher average annual maintenance costs?
- If the school is protected with floodproofing measures, what are the costs of annual inspection, periodic maintenance and replacement of materials, and staff training and drills?
- If the school meets only the minimum elevation requirements, what are the average annual damages and cleanup costs over the anticipated useful life of the building, including the occurrence of floods that exceed the design flood elevation?
- How do long-term costs associated with periodic inundation compare to up-front costs of selecting a different site or building to a higher level of protection?
- If a site outside of the flood hazard area is available but less than optimal in terms of access by the community, are the trade-offs acceptable?

- If the school is located in a hurricane-prone community, how should the school design account for low-probability, but high-impact, storm surge flooding?
- If access to the school is periodically restricted by flooding, especially long-duration flooding, what are the resulting cost effects? How often would the school district have to provide an alternate location to continue classes?

5.3.3 Site Modifications

When sites being considered for schools are determined to be prone to flooding, facility planners and designers may want to evaluate the feasibility of certain site modifications in order to provide an increased level of protection to buildings. The evaluations involve engineering analyses to determine whether the desired level of protection is cost effective, and whether the proposed site modifications alter the floodplain in ways that could increase flooding. The effectiveness of typical site modifications and their ramifications must be examined for each specific site.

Earthen fill: Fill can be placed in the flood hazard area to elevate an entire site above the DFE. If the fill is placed and compacted to be stable during the rise and fall of floodwaters, and if the fill is protected from erosion, then modifying a site with fill to elevate a school is preferred over other methods of elevation. Not only will buildings be less exposed to flood forces, but, under some circumstances (such as long-duration floods), schools may be able to continue to function. Whether nonstructural fill is placed solely to modify the site, or structural fill is placed to elevate buildings, placement of fill can change flooding characteristics, including increased flooding on other properties. Engineering analyses can be conducted to determine whether eliminating floodplain storage by filling will change the direction of the flow of water, create higher flow velocities, or increase the water surface elevation in other parts of the floodplain.

In Coastal A Zones, back bays, and along the banks of wide rivers where wave action is anticipated, fill is a less-effective site modification method because wave action may erode the fill, and adequate armoring or other, protection methods can be expensive.

In V zones, structural fill is not allowed as a method of elevating buildings. Beachfront areas with sand dunes pose special problems. Manmade alterations of sand dunes are not allowed unless analyses indicate that such modifications will not increase potential flood damage.

Excavation: Excavation on a given parcel of land alone rarely results in significant alteration of the floodplain. Excavation that modifies a site is more commonly used in conjunction with fill in order to offset or compensate for the adverse impacts of fill.

Earthen levee: A levee is a specially designed barrier that modifies the floodplain by keeping the water away from certain areas (see Figure 5-21a). Levees are significant structures that require detailed, site-specific geotechnical investigations; engineering analyses to identify whether flooding will be made worse on other properties; structural and site design to suit existing constraints; design of interior drainage (on the land side); and long-term commitment for maintenance, inspection, and repairs. Areas behind levees are protected only up to a certain design flood level—once overtopped or breeched, most levees fail and catastrophic flooding results. Levees that protect schools and other critical facilities usually are designed for at least the 0.2-percent-annual-chance flood (500-year) and have freeboard to increase the factor of safety. Depending on the site layout and duration of flooding, access for vehicles can be problematic. Low levees can be designed with road access; higher levees can be designed with vehicle access points that require special closures when flooding is predicted.

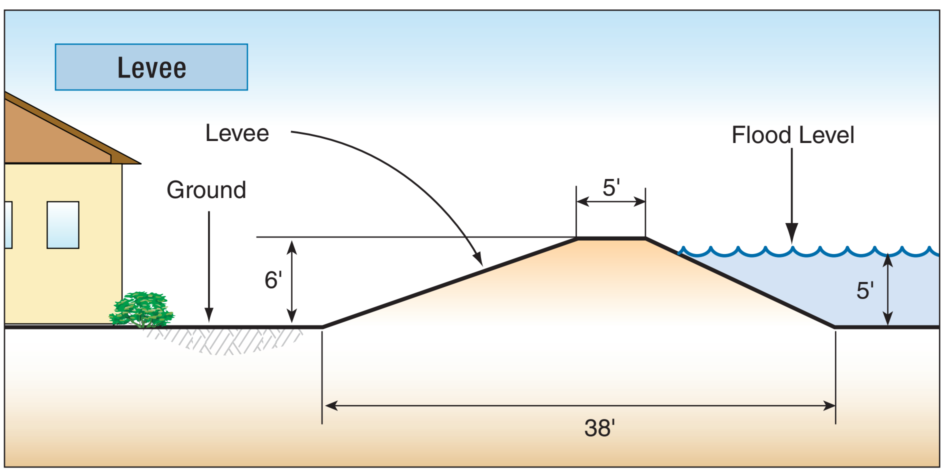


Figure 5-21a: Schematic of typical earthen levee

Floodwall: Floodwalls are similar to levees in that they provide protection to certain areas (see Figure 5-21b). Failure or overtopping of a floodwall can result in catastrophic flooding. A floodwall is a significant structure designed to hold back water of a certain depth based on the design flood for the site. Generally, floodwalls are most effective in areas with relatively shallow flooding and minimal wave action. As with levees, designs must accommodate interior drainage on the land side, and maintenance and operations are critical for adequate performance. Floodwalls that protect buildings that provide essential services usually are designed for the 0.2-percent-annual-chance flood (500-year) and have freeboard to increase the factor of safety. If a protected school is intended to remain operational during long-duration flooding, vehicle access to the site and pedestrian access to the building are required.

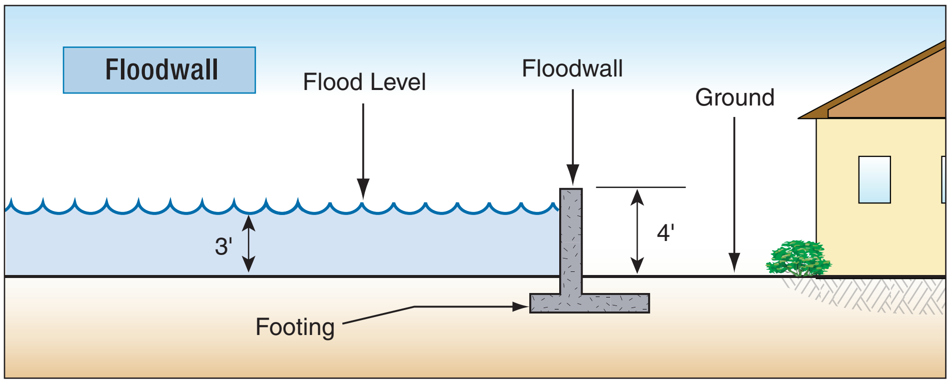


Figure 5-21b: Schematic of typical permanent floodwall

5.3.4 Elevation Considerations

The selection of the appropriate method of elevating a school building in a SFHA depends on many factors, including type of flood zone, costs, level of safety and property protection determined as acceptable risk, and others. Another consideration is the elevation of the lowest floor relative to the flood elevation. Table 5-1 in Section 5.1.6.4 summarizes the elevation requirements in ASCE 24. Given the importance of schools, elevation of the lowest floor to or above the 0.2-percent-annual-chance flood (500-year) elevation should be considered the minimum. Various methods used to elevate buildings in flood hazard areas are described below.

In A zones, the minimum requirement is that the lowest floor (including the basement) be at or above the DFE (plus freeboard, if desired or required). For building elevation methods other than fill, the area under elevated buildings in A zones may be used only for limited purposes. parking, building access, and limited storage (crawlspaces are treated as enclosures, see below). Facility planners and designers are cautioned that enclosures below the DFE are exposed to flooding and the contents will be damaged or destroyed by floodwaters. The walls surrounding an enclosure must have flood openings that are intended to equalize

"**Lowest floor**" is the floor of the lowest enclosed area (including the basement). An unfinished or flood-resistant enclosure, usable solely for parking of vehicles, building access, or storage in an area other than a basement, is not the lowest floor, provided the enclosure is built in compliance with applicable requirements.

interior and exterior water levels in changing flood conditions, to prevent differential hydrostatic pressures leading to structural damage. The enclosed area must not contain utilities and equipment (including ductwork) below the required elevation.

In V zones, the minimum requirement is that the elevation of the bottom of the lowest horizontal structural member of the lowest floor (including basement) be at or above the DFE (plus freeboard, where required). (Use of structural fill to achieve elevation is not allowed and dry floodproofing is not allowed.) Given the importance of schools, elevation to or above the 0.2-percent-annual-chance flood (500-year) elevation is appropriate and strongly recommended. The V zone requirements are recommended in Coastal A Zones.

The area under elevated buildings in V zones may be used only for parking, building access, and limited storage. The areas may be open or enclosed by lattice walls or screening. If areas are enclosed by solid walls, the walls must be specifically designed to break away under certain flood loads to allow the free passage of floodwaters under the building. Breakaway walls are non-load-bearing walls, i.e., they do not provide structural support for the building. They must be designed and constructed to collapse under the pressure of floodwaters in such a way that the supporting foundation system and the structure are not affected.

Communities that participate in the NFIP require that a registered professional engineer or architect develop or review the structural design, specifications, and plans, and certify that the dry floodproofing design and methods of construction to be used are in accordance with accepted standards of practice. The standards of practice require that the building, together with attendant utility and sanitary facilities, be designed so that it is watertight, with walls substantially impermeable to the passage of water and with structural components having the capability of resisting hydrostatic and hydrodynamic loads and effects of buoyancy associated with the design flood event.

Coastal communities along the Atlantic and Gulf coasts are subject to storm surge flooding generated by hurricanes and tropical storms. Depending on a number of variables, storm surge flood depths may significantly exceed the BFE. In addition, waves are likely to be higher than predicted for the base flood, and will occur farther inland in areas where significant wave action during the base flood is not expected. Application of the minimum requirements related to elevation of the lowest floor and foundation design does not result in flood resistance for such extreme conditions. Foundations for schools in areas subject to storm surge should be designed to elevate the building so that the lowest horizontal structural members are higher than the minimum required elevation. Additional elevation not only reduces damage that results from lower probability events, but the cost of Federal flood insurance is usually lower. Facility planners and designers should plan to use the lowest elevated floor for non-critical uses that, even if exposed to flooding more severe than the design flood, will not impair critical functioning during post-flood recovery.

Storm surge flooding and waves can cause scour and erosion, even at locations that are some distance from the shoreline. Foundation designs for schools in coastal communities should account for some erosion and local scour of supporting soil during low-probability surge events. Storm surge flooding can also produce large quantities of floating debris, even at locations that are some distance from the shoreline. Debris can damage nonstructural building components and, in some cases of prolonged battering, can lead to structural failure. Foundation designs for schools in coastal communities should account for debris loads. This is especially important where damage to other buildings in the area may generate additional debris, thereby increasing the loads.

Notes on continuous load path: In coastal communities and other areas exposed to high winds, designers should pay special attention to the entire roof-to-foundation load path when designing and specifying connections. Connections must be capable of withstanding simultaneous wind and flood forces. Poorly connected buildings may fail or float off foundations when floodwaters and waves are higher than the design flood elevation. Corrosion-resistant connections are critical for the long-term integrity of the structure, and should be inspected and maintained regularly.

Slab-on-grade foundation on structural fill: This is considered to be the safest method to elevate a building in many flood hazard areas, except those where waves and high velocity flows may cause erosion. Consequently, this foundation type is not allowed in V zones. Structural fill can be placed so that even if water rises up to the DFE, the building (see Figure 5-22) and building access would still be protected from flooding. The fill must be designed to minimize adverse impacts, such as increasing flood elevations on adjacent properties, increasing erosive velocities, and causing local drainage problems. To ensure stability, especially as floodwaters recede and the soils drain, fill must be designed for the anticipated water depths and duration. A geotechnical engineer or soil scientist may need to examine underlying soils to determine if the bearing capacity is sufficient to carry the added weight of fill, or if consolidation over time may occur. In addition, the effects of long-term compaction of the fill should be considered, and may prompt additional elevation as a factor of safety. The horizontal extent of the fill, away from the foundation, should be designed to facilitate access by emergency vehicles, with a minimum 25-foot width recommended. Engineered concrete slabs supported by piers should have sufficient resistance to erosion and scour if designed for anticipated flood conditions. Designers are cautioned to avoid excavating a basement into fill without added structural protection (and certification that the design meets the requirements for dry floodproofing), due to the potential for significant hydrostatic loads and uplift on basement floors.

Figure 5-22: High school in Bloomsburg, PA, elevated on fill

Stem wall foundations: Stem wall foundations have a continuous perimeter grade beam, or perimeter foundation wall, that is backfilled with compacted earth to the underside of the concrete floor slab (see Figure 5-23). This foundation type is not allowed in V zones. Stem wall foundations are designed to come in contact with floodwaters on the exterior. They are more stable than perimeter wall foundations with crawlspaces, but could experience structural damage if undermined by local scour and erosion. Designs must account for anticipated debris and ice impacts, and incorporate methods and materials to minimize impact damage.

Columns or shear wall foundations (open foundations): Open foundations consist of vertical load-bearing members (columns, piers, pilings, and shear walls) without solid walls connecting the vertical members. Open foundations minimize changes to the floodplain and local drainage patterns, and the area under the building can be used for parking or student activities (see Figure 5-24). The design of the vertical members must also account for hydrodynamic loads and debris and ice impact loads. Flood loads on shear walls are reduced if they are oriented parallel to the anticipated direction of flow. If erodible soils are present and local scour is likely, both conditions must be taken into account when determining embedment depth of the vertical foundation members. Depending on the total height of the elevated school, the design may need to take into consideration the increased exposure to wind and uplift, particularly where loads are expected from breaking waves.

Figure 5-23: A stemwall foundation elevates the Marion T. Academy above the flood level in Wilmington, DE.

Figure 5-24: School elevated on columns

In V zones, buildings must be elevated using open foundations, which consist of vertical load-bearing members (columns, piers, pilings, and shear walls) without solid walls connecting the vertical members. The design of the vertical members must also account for hydrodynamic loads and debris impact loads. Flood loads on shear walls are reduced if the walls are oriented parallel to the anticipated direction of flow. Erodible soils may be present and local scour may occur; both must be accounted for in designs by extending the load-bearing members and foundation elements well below the expected scour depth.

Continuous perimeter walls (enclosed foundations with crawlspace): Unlike stem wall foundations, continuous perimeter walls enclose an open area or crawlspace (see Figure 5-25). The perimeter walls must have flood openings, also called vents) that are intended to equalize interior and exterior water levels automatically during periods of rising and falling flood levels, to prevent differential hydrostatic pressures that could lead to structural damage. Flood openings may be engineered and certified for the required performance, or they must meet prescriptive requirements (notably, the opening must provide at least 1 square inch of net open area for each square foot of area enclosed). Perimeter wall design must also account for hydrodynamic loads, and debris and ice impact loads. Enclosed crawlspaces must not contain utilities or equipment

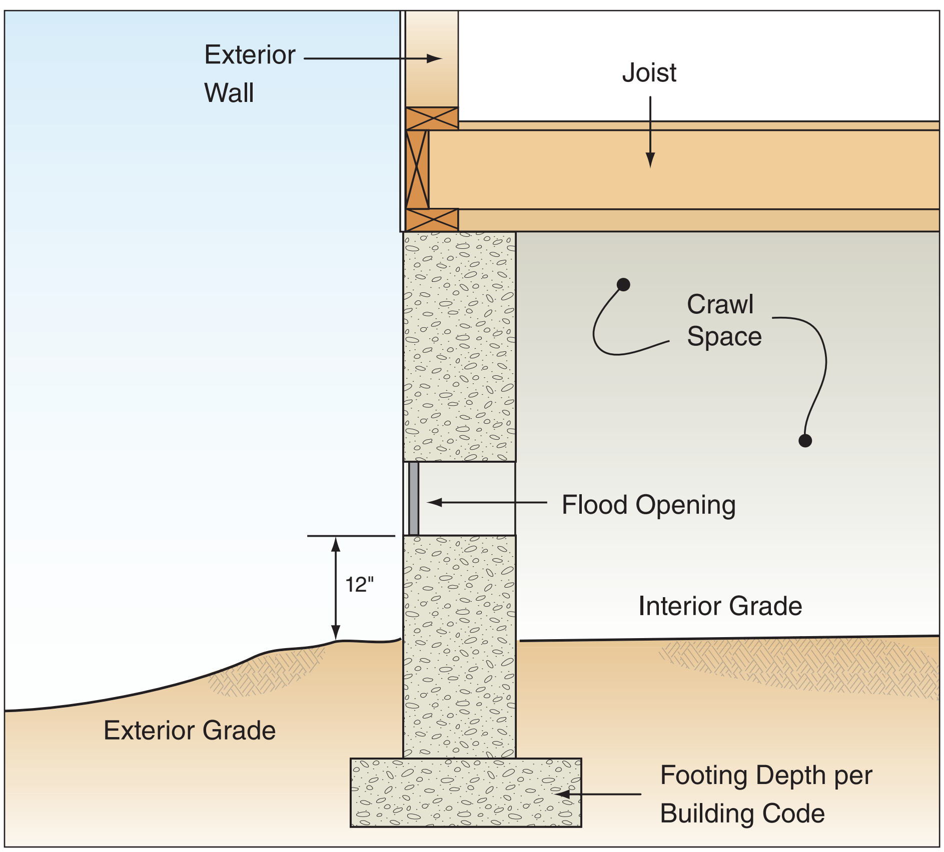


Figure 5-25: Typical crawlspace with flood openings

(including ductwork) below the required elevation. Designers must provide adequate under-floor ventilation and subsurface drainage to minimize moisture problems after flooding. This foundation type is not allowed in V zones.

Pier supports for manufactured and portable units: Manufactured buildings and portable units must be elevated above the DFE (plus freeboard, if required). Pier supports must account for hydrodynamic loads and debris and ice impact loads, and units must be anchored to resist wind loads. Although written specifically for manufactured housing units, FEMA P-85, *Protecting Manufactured Homes from Floods and Other Hazards. A Multi-Hazard Foundation and Installation Guide* (2009b), has useful information that is applicable to portable units.

5.3.5 Dry Floodproofing Considerations

Dry floodproofing involves a combination of design and special features that are intended both to prevent water infiltration and resist flood forces. It involves structural reinforcement so that exterior walls are sufficiently robust to withstand the loads described in Section 5.1.3 (hydrostatic pressure, hydrodynamic loads, wave loads, and debris impact loads). Exterior walls must also be designed to prevent infiltration and seepage of water, whether through the wall itself or through any openings, including where utility lines penetrate the envelope. Floodproofing techniques are considered to be permanent measures if they are always in place and do not require occupants to take any specific actions to be effective. An alternative to reinforcement of a structure's walls involves the installation of a permanent floodwall that is slightly offset from the exterior of the structure, but designed to be integral to the foundation.

According to the model building codes and the NFIP regulations, non-residential buildings and nonresidential portions of mixed-use buildings in A zones may be dry floodproofed. Although floodproofing is allowed, careful consideration must be given to the possible risks to occupants and additional physical damage before a decision is made to construct a new school using floodproofing methods. Dry floodproofing is not allowed in V zones.

All flood protection measures are designed for certain flood conditions. Considering the possibility that the design conditions can be exceeded (i.e., water can rise higher than the protective structures),

> Communities that participate in the NFIP require that a registered professional engineer or architect develop or review the structural design, specifications, and plans, and certify that the dry floodproofing design and methods of construction to be used are in accordance with accepted standards of practice. The standards of practice require that the building, together with attendant utility and sanitary facilities, be designed so that it is watertight, with walls substantially impermeable to the passage of water and with structural components having the capability of resisting hydrostatic and hydrodynamic loads and effects of buoyancy associated with the design flood event.

a dry floodproofed building may, in such circumstances, sustain catastrophic damage. As a general rule, dry floodproofing is a poor choice for new schools when avoidance of the floodplain or elevation methods to raise the building above the flood level can be applied. Floodproofing may be acceptable for retrofitting existing buildings under very limited circumstances (see Section 5.4.5).

A number of dry floodproofing limitations and requirements are specified in ASCE 24:

- Dry floodproofing is limited to areas where flood velocities at the site are less than or equal to 5 feet per second.
- If human intervention is required to deploy measures to protect doors and windows, the flood warning time shall be a minimum of 12 hours unless the community operates a flood warning system and implements a notification procedure that provides sufficient time to undertake these measures.
- At least one door satisfying building code requirements for an exit door or primary means of escape must be provided above the level of protection.
- An emergency plan, approved by the community and posted in at least two conspicuous locations, is required in floodproofed buildings; the plan is intended to specify the location of panels and hardware, methods of installation, conditions that activate deployment, a schedule for routine maintenance of any aspect that may deteriorate over time, and periodic practices and drills.

Windows, doors, and other openings that are below the flood level used for dry floodproofing design present significant potential failure points. They must be specially designed units (see Figure 5-26) or be fitted with gasketed, mountable panels that are designed for the anticipated flood conditions and loads. Generally speaking, protecting window and door openings from water more than a few feet deep is difficult. The framing and connections must be specifically designed for these protective measures, or water pressure may cause window and door frames to separate from the building.

Dry floodproofing is required to extend to 1 or 2 feet above the DFE (see Table 5-1). For the purpose of obtaining NFIP flood insurance, the floodproofing must extend at least 1 foot above the BFE, or the premiums will be very high. A higher level of protection is recommended.

Although dry floodproofing of facilities in Coastal A Zones is allowed by the NFIP, designs that comply with the IBC must take into consideration the additional forces associated with wave impacts, which may make dry floodproofing a less feasible alternative.

Figure 5-26: Specially designed panels are mounted to block doors, windows, and other openings to keep water from entering the building.

Floodproofing techniques are considered to be permanent measures if they are always in place and do not require any specific human intervening action to be effective. Use of contingent floodproofing measures that require installation or activation, such as window shields or inflatable barriers, may significantly reduce the certainty that floodproofing will be effective. Rigorous adherence to a periodic maintenance plan is critical to ensure proper functioning. If these measures are used to protect schools, the school's management must have a formal, written plan, and the people responsible for implementing the measures must be informed and trained. These measures also depend on the timeliness and credibility of the warning. In addition, floodproofing devices often rely on flexible seals that require periodic maintenance and that, over time, may deteriorate and become ineffective. Therefore, a maintenance plan must be developed and a rigorous annual inspection and training must be conducted.

Dry floodproofed schools must never be considered safe for occupancy during periods of high water; floodproofing measures are intended only to reduce physical damage.

Safety of occupants is a significant concern with dry floodproofed buildings, because failure or overtopping of the floodproofing barriers is likely to cause catastrophic structural damage. When human intervention is required for deploying of barriers, those responsible for implementing the measures remain at risk while at the school, even if a credible warning system is in place, because of the many uncertainties associated with predicting the onset of flood conditions.

5.3.6 Flood Damage-Resistant Materials

All structural materials, nonstructural materials, and connectors that are used below certain elevations (see Table 5-1) are to be flood resistant. Flood-damage-resistant materials have sufficient strength, rigidity, and durability to adequately resist flood loads and damage due to saturation. They are building materials that are capable of withstanding direct and prolonged contact with floodwaters without sustaining any damage that requires more than cosmetic repair. As defined in ASCE 24, the term "prolonged contact" means partial or total inundation by floodwaters for 72 hours for non-coastal areas (fresh water) or 12 hours for coastal areas.

In general, materials that are exposed to floodwaters are to be capable of resisting damage, deterioration, corrosion, or decay. Typical construction materials range from highly resistant to not at all resistant to water damage. FEMA NFIP Technical Bulletin 2 contains tables with building materials, classified based on flood resistance (Table 5-2).

Table 5-2: Classes of flood damage-resistant materials

NFIP	Class	Class Description
Acceptable	5	**Highly resistant to floodwater[1] damage, including damage caused by moving water.[2]** These materials can survive wetting and drying and may be successfully cleaned after a flood to render them free of most harmful pollutants.[3] Materials in this class are permitted for partially enclosed or outside uses with essentially unmitigated flood exposure.
	4	**Resistant to floodwater[1] damage from wetting and drying, but less durable when exposed to moving water.[2]** These materials can survive wetting and drying and may be successfully cleaned after a flood to render them free of most harmful pollutants.[3] Materials in this class may be exposed to and/or submerged in floodwaters in interior spaces and do not require special waterproofing protection.
Unacceptable	3	**Resistant to clean water[4] damage, but not floodwater damage.** Materials in this class may be submerged in clean water during periods of flooding. These materials can survive wetting and drying, but may not be able to be successfully cleaned after floods to render them free of most[3] harmful pollutants.
	2	**Not resistant to clean water[4] damage.** Materials in this class are used in predominantly dry spaces that may be subject to occasional water vapor and/or slight seepage. These materials cannot survive the wetting and drying associated with floods.
	1	**Not resistant to clean water[4] damage or moisture damage.** Materials in this class are used in spaces with conditions of complete dryness. These materials cannot survive the wetting and drying associated with floods.

Notes:

1. Floodwater is assumed to be considered "black" water; black water contains pollutants such as sewage, chemicals, heavy metals, or other toxic substances that are potentially hazardous to humans.
2. Moving water is defined as water moving at low velocities of 5 feet per second (fps) or less. Water moving at velocities greater than 5 fps may cause structural damage to building materials.
3. Some materials can be successfully cleaned of most of the pollutants typically found in floodwater. However, some individual pollutants such as heating oil can be extremely difficult to remove from uncoated concrete. These materials are flood damage-resistant except when exposed to individual pollutants that cannot be successfully cleaned.
4. Clean water includes potable water as well as "gray" water; gray water is wastewater collected from normal uses (laundry, bathing, food preparation, etc.).

SOURCE. *FLOOD DAMAGE-RESISTANT MATERIALS REQUIREMENTS*, FEMA-TB-2, AUGUST 2008.

FEMA NFIP Technical Bulletin 2, *Flood Damage-Resistant Materials Requirements* (2008), provides some additional information. Many types of materials and application products are classified by degrees of resistance to flood.

In coastal areas, airborne salt aerosols and inundation with saline water increase the potential for corrosion of some metals. Structural steel and other metal components that are exposed to corrosive environments should be stainless steel or hot-dipped galvanized after fabrication.

In areas away from the coast, exposed structural steel should be primed, coated, plated, or otherwise protected against corrosion. Secondary components such as angles, bars, straps, and anchoring devices, as well as other metal components (plates, connectors, screws, bolts, nails angles, bars, straps, and the like) should be stainless steel or hot-dipped galvanized after fabrication.

Concrete and masonry that are designed and constructed in compliance with applicable standards are generally considered to be flood resistant. However, masonry facings are undesirable finishes unless extra anchoring is added to prevent separation (see Figure 5-27). Wood and timber members exposed to floodwaters should be naturally decay-resistant species, or should be pressure treated with appropriate preservatives.

Figure 5-27: Brick facing separated from masonry wall (Hurricane Katrina, 2005)

5.3.7 Access Roads

Roads and entrances leading to schools should be designed to provide safe access at all times, to minimize impacts on flood hazard areas, to minimize damage to the road itself, and to minimize exposing vehicles to dangerous situations. Even if the school is elevated and protected from flood damage, when access is impaired, functionality is also impaired. Facility planners and designers should take the following factors into consideration.

Safety factors: Although a school's access road off the primary surface street may not be required to carry regular traffic like other streets, a floodprone road always presents a degree of risk to public safety. To minimize those risks, some State or local regulatory authorities require that access roads be designed so that the driving surface is at the DFE, or no more than 1 to 2 feet below the DFE. At a minimum, a school's access road should be at least as high as the adjacent public road, so that the same level of access is provided during conditions of flooding. To maximize evacuation safety, two separate access roads to different feeder roads are recommended. In some circumstances, especially long-duration flooding where a school is built on fill, access roads designed to be above flood levels would help the school to continue its operations.

Floodplain impacts: Engineering analyses may be required to determine the effects on flood elevations and flow patterns if large volumes of fill are required to elevate a road to minimize or eliminate flooding above the driving surface.

Drainage structure and road surface design: The placement of multiple drainage culverts, even if not needed for local drainage, can facilitate the passage of floodwaters and minimize the potential for a road embankment to act as a dam. Alternatively, an access road can be designed with a low section over which rising floodwater can flow without washing out the roadbed. Embankments should be designed to remain stable during high water and as waters recede. They should be sloped and protected to resist erosion and scour. Similarly, the surface and shoulders of roads that are intended to flood should be designed to resist erosion. The increased resistance to erosion may be accomplished by increasing the thickness of the road base.

5.3.8 Utility Installations

Utilities associated with new schools in flood hazard areas must be protected either by elevation or special designs and installation measures. Utilities subject to this provision include all systems, equipment, and fixtures, including mechanical, electrical, plumbing, heating, ventilating, and air-conditioning. Potable water systems (wellheads and distribution lines) and wastewater collection lines are addressed in Section 5.3.9.

Utility systems and equipment are best protected when elevated above the DFE (plus freeboard, if required). Equipment that is required for emergency functioning during or immediately after an event, such as emergency generators and fuel tanks, is best installed well above the DFE. In some cases, equipment can be located inside protective floodproofed enclosures, although if flooding exceeds the design level of the enclosure, the equipment would be adversely affected (see Figure 5-28). Designers should pay particular attention to under-floor utilities and ductwork to ensure that they are properly elevated. Plumbing conduits, water supply lines, gas lines, and electric cables that must extend below the DFE should be located, anchored, and protected to resist the effects of flooding. Equipment that is outside of an elevated building also must be elevated:

For more information on utility installations, see FEMA 348, *Protecting Building Utilities from Flood Damage: Principles and Practices for the Design and Construction of Resistant Building Utility Systems* (1999).

- In A zones, equipment may be affixed to raised support structures or mounted on platforms that are attached to or cantilevered from the primary structure.

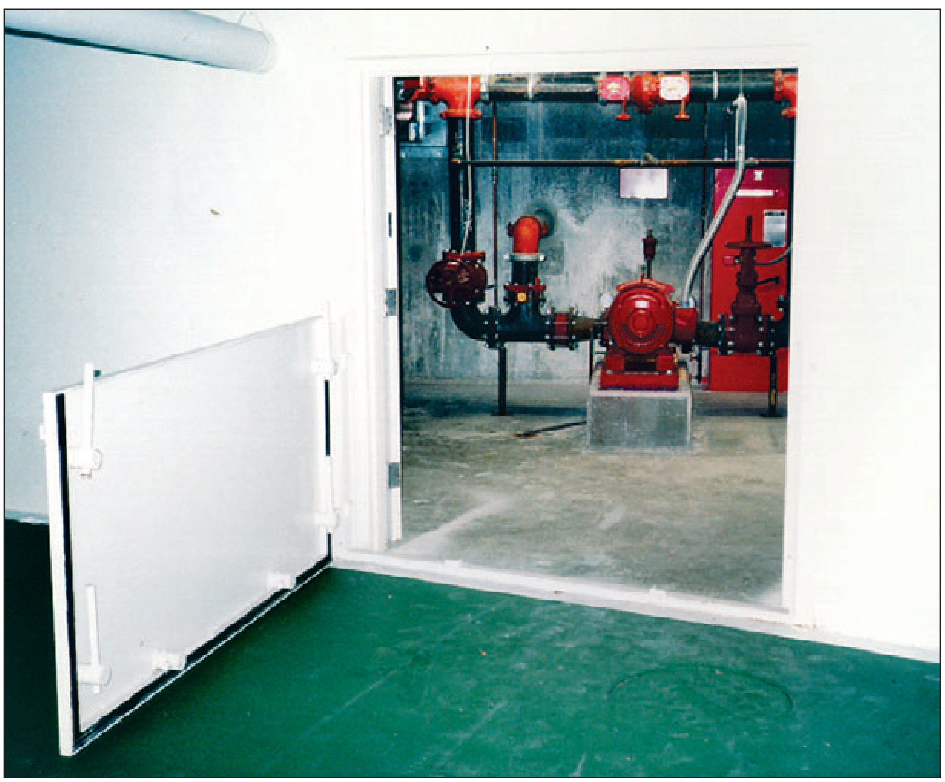


Figure 5-28: Equipment room with watertight door

SOURCE: PRESRAY CORPORATION

- In V zones and Coastal A Zones, equipment may be affixed to raised support structures designed for the flood conditions (waves, debris impact, erosion, and scour) or mounted on platforms that are attached to or cantilevered from the primary structure. If an enclosure is constructed under the elevated building, the designer must take care that utilities and attendant equipment are not mounted on or do not pass through walls that are intended to break away.

Although it is difficult to achieve, the model building codes and NFIP regulations provide an alternative that allows equipment to be located below the DFE. This alternative requires that such equipment be designed, constructed, and installed to prevent floodwaters from entering or accumulating within the components during flood events.

5.3.9 Potable Water and Wastewater Systems

New installations of potable water systems and wastewater collection systems are required to resist flood damage, including damage associated with infiltration of floodwaters and discharge of effluent. Health concerns arise when water supply systems are exposed to floodwaters. Contamination from flooded sewage systems poses additional health and environmental risks. Onsite water supply wellheads should be located on land elevated from the surrounding landscape to allow contaminated surface water and rainfall-runoff to drain away. Well casings should extend above the DFE, and casings should be sealed with a tight-fitting, floodproof, and vermin-proof well cap. The space between the well casing and the side of the well must be sealed to minimize infiltration and contamination by surface waters.

Sewer collection lines should be located and designed to avoid infiltration and backup due to rising floodwaters. Devices designed to prevent backup are available and are recommended to provide an added measure of protection.

Onsite sewage systems usually are not used as the primary sewage disposal systems for new schools. However, facility planners and designers should consider a backup onsite system if a school's functionality can be impaired when the public system is affected by flooding. Local or State health departments may impose constraints that limit or prevent locating septic fields in floodplain soils or within a mapped flood hazard area. If allowed, septic fields should be located on the highest available ground to minimize inundation and damage by floodwaters. An alternative to a septic field is installation of a holding tank that is sized to contain wastewater for a period of time, perhaps a few days, while the municipal system is out of service.

5.3.10 Storage Tank Installations

Aboveground and underground storage tanks located in flood hazard areas must be designed to resist flotation, collapse, and lateral movement. ASCE 24 specifies that aboveground tanks be elevated or constructed, installed, and anchored to resist at least 1.5 times the potential buoyant and other flood forces under design flood conditions, assuming the tanks are empty. Similarly, underground tanks are to be anchored to resist at least 1.5 times the potential buoyant forces under design flood conditions, assuming the tanks are empty. In all cases, designers are cautioned to address hydrodynamic loads and debris impact loads that may affect tanks that are exposed to floodwaters. Vents and fill openings or cleanouts should be elevated above the DFE or designed to prevent the inflow of floodwaters or outflow of the contents of tanks.

5.3.11 Accessory Structures

Many school campuses have multiple buildings. All buildings, including those that are accessory to the primary building, must be designed and constructed in full compliance with floodplain management regulations. Portable classrooms are not accessory structures. Bleachers are allowed provided they are anchored to resist flood forces.

In flood hazard areas designated as A zones, some minor accessory structures used only for storage and parking need not fully comply, but may be "wet floodproofed" using techniques that allow them to flood while minimizing damage. Accessory structures must be anchored to resist flotation, collapse, and lateral movement. Flood-resistant materials must be used and utilities must be elevated above the DFE (plus freeboard, if required). If fully enclosed by walls, the walls must have flood openings to allow the free inflow and outflow of floodwaters to minimize the hydrostatic loads. Because wet floodproofed accessory buildings are designed to flood, school staff must be aware that contents will be damaged.

Accessory structures on school campuses that are located in V zones must be elevated and otherwise comply with the applicable requirements.

5.4 Risk Reduction for Existing Schools

5.4.1 Introduction

Section 5.2 describes damage that can be sustained by schools that already are located in flood hazard areas. The vulnerability of these facilities can be reduced if they can be made more resistant to flooding. School districts may take such action when flood hazards are identified and there is a desire to undertake risk reduction measures proactively. Interest may be prompted by a flood or by the requirement to address flood resistance as part of a proposed addition or substantial improvement of the existing building. The checklist in Section 5.6 includes some questions and guidance intended to help identify building characteristics of importance when considering risk reduction measures for existing facilities.

Work performed on existing school buildings and outbuildings is subject to codes and regulations, and the appropriate regulatory authority with jurisdiction should be consulted. With respect to reducing flood risks, work generally falls into the categories described in the following subsections.

School districts should be aware of the importance of flood insurance coverage for structures that are located in the flood hazard areas shown on NFIP maps. If not insured for flood peril, the amount of flood insurance that should have been in place will be deducted from any Federal disaster assistance payment that would otherwise have been made available. A district may have to absorb up to $1 million in un-reimbursable flood losses per building, because the NFIP offers $500,000 in building coverage and $500,000 in contents coverage for nonresidential buildings (coverage limits as of early 2010).

5.4.2 Site Modifications

Modifying the site of an existing school property that is subject to flooding requires careful examination by an experienced professional engineer. Determining the suitability of a specific measure requires a complex evaluation of many factors, including the nature of flooding and the nature of the site. The first part of Table 5-3 in Section 5.6 identifies elements that influence the choice of mitigation measures applicable to existing sites. Some flood characteristics may make it infeasible to apply site modification measures to existing schools (e.g., depths greater than 3 to 4 feet, very high velocities, insufficient warning because of flash flooding or rapid rate of rise, and very long duration). In Coastal A Zones, wave conditions must be accounted for in design of site modifications. Such modifications are not allowed in V zones.

A common problem with all site modifications is the matter of access. Depending on the topography of the site, construction of barriers to floodwaters may require special access points. Access points may be protected with manually installed stop-logs or designed gates that drop in, slide, or float into place. Whether activated by automatic systems or manually operated, access protection requires sufficient warning time.

Other significant constraining factors include poor soils and insufficient land area, which can make site modifications either infeasible or very costly. For any type of barrier, rainfall that collects on the dry side must be accounted for in the design, whether through adequately sized stormwater storage basins set aside for this purpose, or

Schools protected by local berms, levees, and floodwalls should never be occupied during flood conditions. The consequences of failure or flood levels overtopping these measures can be catastrophic and create high-risk conditions.

by providing large-capacity pumps to move collected drainage to the water side of the barrier.

Each of the site modification measures described below has limitations, including the fact that floods larger than the design flood will exceed the level of protection.

Site regrading (berm): Regrading of the site, or the construction of an earthen berm, may provide adequate protection for situations in which a school is exposed to relatively shallow flooding, and sufficient land area is available.

Earthen levee: Earthen levees are engineered structures that are designed to keep water away from certain areas and buildings. Hydraulic analyses and geotechnical investigations are required to determine their feasibility and effectiveness. The use of earthen levees to protect existing schools is constrained by the availability of land (levees have a large "footprint" and require large land areas), cost (including availability of suitable fill material and long-term maintenance), and access difficulties. Locating levees and floodwalls within a designated floodway is generally not allowed. Rapid onset flooding makes it impractical to design a flood levee with access points that require installation of a closure system. Additionally, high velocity flows can cause erosion and reduce the stability of earthen levees.

Permanent floodwall: Floodwalls are freestanding, permanent engineered structures designed to prevent encroachment of floodwaters. Typically, a floodwall is located some distance from a building, so that structural modification of the existing building is not required. Depending on the topography of the site, floodwalls may protect only the low side (in which case they must "tie" into high ground) or completely surround a site (which may affect access because special closure structures are required and must be installed before the onset of flooding, see Figure 5-29).

Mobilized floodwall: This category of flood protection measures includes fully engineered flood protection structures that have permanent features (foundation and vertical supports) and features that require human intervention when a flood is predicted (horizontal components called planks or stop-logs). Mobilized floodwalls have been used to protect entire sites, or to tie into permanent floodwalls or high ground. Because of the manpower and time required for proper placement, these measures are better suited to conditions that allow long warning times.

Figure 5-29: A masonry floodwall with multiple engineered openings in Fargo, ND, during flooding in 2001

SOURCE: FLOOD CONTROL AMERICA, LLC

5.4.3 Additions

Model building codes generally treat additions as new construction, and thus additions to schools in flood hazard areas should be elevated or dry floodproofed to minimize exposure to flooding. However, full compliance with the code and NFIP requirements is only required if an addition is a substantial improvement (i.e., the cost of the addition plus all other costs associated with the work equal or exceed 50 percent of the market value of the building, see Section 5.1.6.1 and Section 5.1.6.2). Designers are cautioned that even the existing buildings may be required to comply with the flood-resistant provisions of the code or local ordinances, if the addition is structurally connected to the existing building and is determined to be a substantial improvement.

Section 5.3.4 outlines foundation methods used to elevate buildings that also are applicable to additions. Elevation of an addition on fill may not be feasible unless structural fill can be placed adjacent to the existing building. Utility service equipment for additions must meet the requirements for new installations (see Section 5.3.8).

If an evaluation determines that dry floodproofing is appropriate, additions may be floodproofed (see Section 5.3.5). To provide adequate protection for the addition, floodproofing must be applied to all exterior walls and the wall adjoining the existing building. Openings, including doors between the addition and existing building, must also be protected.

For more information on additions and substantial improvements, see FEMA P-758, *Substantial Improvement/Substantial Damage Desk Reference* (2010) and FEMA 213, *Answers to Questions About Substantially Damaged Buildings* (1991).

With respect to code compliance and designing additions to resist flood damage, one of the more significant issues to be considered is ease of access. If the lowest floor of the existing school building is below the DFE, steps, ramps, or elevators will be required for the transition to the new addition. Some jurisdictions may contemplate allowing variances to the requirement that additions be elevated. However, because alternative means of access are available, such as ramps and elevators it would be difficult for an applicant to demonstrate that there are unique limitations of the site and hardship that make compliance with the regulation infeasible.

5.4.4 Repairs, Renovations, and Upgrades

Every school considered for upgrades and renovations, or being repaired after substantial damage from any cause, must be examined for structural integrity and stability to determine compatibility with structural modifications that may be required to achieve acceptable performance. When an existing school is located in a flood hazard area, that examination should include consideration of measures to improve resistance to flood damage and to reduce risks.

The model building codes and the NFIP regulations require that work constituting "substantial improvement" of an existing building be in compliance with the flood-resistant provisions of the code. Non-substantial improvements should take into account measures to reduce future flood damage, such as those described in Section 5.3, emergency measures (see Section 5.4.10), and wet floodproofing measures that allow water to enter the building to avoid structural damage.

Additional information on rehabilitation of existing buildings is provided in: *Flood Proofing: How to Evaluate Your Options* (USACE, 1993), FEMA 102, *Floodproofing Non-Residential Structures* (1986), FEMA TB-3, *Floodproofing—Requirements and Certification* (1993), and FEMA 259, *Engineering Principles and Practices for Retrofitting Flood Prone Buildings* (2001). Although written primarily for homes, this last reference contains very detailed checklists and worksheets that can be modified. They also provide some guidance for evaluating the costs and benefits of various measures.

Compliance with flood-resistant provisions means that the existing building must be elevated or dry floodproofed. Both options can be difficult for existing schools, given the typical use, size, and complexity of many school buildings. Retrofit dry floodproofing (described in Section 5.4.5) is generally feasible only in areas where flood depths of 3 feet or less are expected, provided an assessment by a qualified design professional determines that the building is capable of resisting the anticipated loads, or can be modified to provide that level of performance.

Elevating an existing building presents an entirely different set of challenges and also requires detailed structural engineering analyses. It involves the same equipment and methods used to move other types of buildings; expert building movers have successfully moved large, heavy, and complex buildings, sometimes by segmenting them. A building that is elevated in-place must meet the same performance standards set for new construction.

5.4.5 Retrofit Dry Floodproofing

Modification of an existing building may be required or desired in order to address exposure to design flood conditions. Modifications that may be considered include construction of a reinforced supplementary wall, measures to counter buoyancy (especially if there is below-grade space), installation of special watertight door and window barriers and watertight seals around the points of entry of utility lines. The details of structural investigations and structural design of such protection measures are beyond the scope of this manual.

"**Dry floodproofing**" refers to measures and methods to render a building envelope substantially impermeable to floodwater.

Retrofit dry floodproofing is difficult to apply to existing buildings and, in general, is limited to situations where the anticipated flood depths are only 3 or 4 feet. Because of the tremendous flood loads that may be exerted on a building not originally designed to keep water out, detailed structural engineering evaluations are required to determine whether an existing building can be dry floodproofed. The following elements must be examined:

- The strength of the structural system
- Whether non-load bearing walls can resist anticipated flood loads; secondary walls can be constructed immediately adjacent to existing walls, with a waterproof membrane, to provide adequate strength
- The effects of hydrostatic pressures on the walls and floors of below-grade areas
- Effective means to install watertight doors and windows, or mountable panels
- Protection where utilities enter the building
- Methods to address seepage, especially where long-duration flooding is anticipated
- Whether there is sufficient time for deployment of measures that require human intervention, given the availability of official warnings of predicted flood conditions

Application of waterproofing products or membranes directly to exterior walls may minimize infiltration of water; although there are concerns with durability and limitations on use (this measure is most effective for shallow, short-duration flooding). Some protection can be achieved using emergency measures that are not designed to be integral to the building (see Section 5.4.10).

5.4.6 Utility Installations

Some features of utility systems in existing schools that are prone to flooding may need to be modified to reduce damage. The effectiveness of such measures depends not only on the nature of the flooding, but the type of service and the degree of exposure. Table 5-3 in Section 5.6 lists some questions to help school facility planners and designers examine risk reduction measures.

Even if a school building is unlikely to sustain extensive structural damage from flooding, significant recovery costs and delayed re-occupancy may result if utility systems are damaged. The damage reduction measures described below can be applied, whether undertaken as part of large-scale retrofits of existing buildings or as separate projects.

Relocate from below-grade areas: The most vulnerable utility installations are those located below grade, and the most effective protection measure is to relocate them to higher floors or platforms that are at least 2 feet above the DFE. The complexity of rerouting pipes, conduits, ductwork, electrical service, lines, and connections will depend on building- and site-specific factors.

Elevate components: Whether located inside or outside of the building, some components of utility systems can be elevated in place on platforms, including electric transformers, communication switch boxes, water heaters, air-conditioning compressors, generators, furnaces, boilers, and heat pumps (see Figure 5-30).

Anchor tanks and raise openings: Existing tanks can be elevated or anchored, as described in Section 5.3.10. If anchored below the DFE, tank inlets, vents, fill pipes, and openings should be elevated above the DFE, or fitted with covers designed to prevent the inflow of floodwaters or outflow of the tank's contents.

Protect components: If utility components cannot be elevated, it may be feasible to construct watertight enclosures, or enclosures with watertight seals that require human intervention to install when flooding is predicted.

Figure 5-30:
Utility component elevated above flood level

Elevate control equipment: Control panels, gas meters, and electrical panels can be elevated, even if the equipment they service cannot be protected.

Separate electrical controls: Where areas within an existing school are floodprone, separation of control panels and electrical feeders will facilitate shutdown before floodwaters arrive, and help protect workers during cleanup.

Protect against electrical surges: Current fluctuations and service interruptions are common in areas affected by flooding. Equipment and sensitive electrical components can be protected by installing surge protection and uninterruptible power supplies.

Connections for portable generators: Prewired portable generator connections allow for quick, failure-free connection and disconnection of the generators when needed for continued functionality.

5.4.7 Potable Water and Wastewater Systems

All plumbing fixtures connected to the potable water system may become weak points in the system if they allow floodwaters to contaminate the system. Relocating the fixtures and services that require plumbing to elevated floors and removing the fixtures that are below the DFE provides protection. Wellheads can be sealed with watertight casings or protected within sealed enclosures.

Wastewater system components become sources of contamination during floods. Rising floodwaters may force untreated sewage to backup through toilets. Specially designed devices that prevent backflow can be installed, or restrooms below the DFE can be provided with overhead piping that may require specially designed pumps to operate properly. Septic tanks can be sealed and anchored.

5.4.8 Other Damage Reduction Measures

A number of steps can be taken to make existing facilities in flood hazard areas more resistant to flood damage, which also facilitates rapid recovery, cleanup, and re-occupancy. Whether these measures can be used for a specific school depends, in part, on the characteristics of the flood hazard and the characteristics of the building itself. School facility planners and designers should consider the following measures:

- Rehabilitate and retrofit the building envelope with openings specifically designed to allow floodwaters to flow in and out to minimize hydrostatic pressure on walls (called wet floodproofing). Although it allows water to enter the building, this measure minimizes the likelihood of major structural damage. Walls that enclose interior spaces should also be retrofitted with openings. Note that this approach is not acceptable when full compliance is required, such as when an existing building is substantially improved or when a new addition is constructed.
- Replace interior walls that have cavities with flood-resistant construction or removable panels to facilitate cleanup and drying.
- Abandon the use of below-grade areas (basements) and fill them in to prevent structural damage.
- Permanently relocate high-value or sensitive functions that are often found on the ground floor of schools (e.g., offices, school records, libraries, and computer laboratories) to higher floors or elevated additions.
- Install backflow devices in sewer lines.

- Preplan actions to move damageable furniture and high-value contents from the lower floors to higher floors when a flood warning is issued.
- Replace wall, flooring, and finish materials with flood-resistant materials. Concrete floors with a sealed, polished, or terrazzo finish have few maintenance requirements, but tend to be slippery when wet.
- Use epoxy or other impervious paints on concrete and other permeable surfaces to minimize contamination.
- Install separate electric circuits and ground fault circuit interrupter protection in areas that will flood. Emergency measures should be provided so that electrical service can be shut down to avoid electrocution hazards.
- Relocate chemicals to storage areas not subject to flooding.

5.4.9 Drainage Improvements

Although drainage improvements will not alleviate flooding caused by rising waters that surround a building, such improvements will help to minimize water damage that can be caused by heavy rainfall. The flow of rainfall-runoff depends on the shape of the land around a school building and the adequacy of the drainage system. Rainfall-runoff will either follow pre-determined paths (above-ground gutters and swales and underground pipes) to intended outfalls, or it may overwhelm the drainage system and enter buildings. Significant damage can be attributed to undersized, poorly planned, or inadequately maintained drainage systems.

Local grading ordinances and stormwater management regulations often require drainage systems to handle the runoff that is associated with the 10-year frequency, 24-hour rainfall event. When heavier rainfall occurs or storms last longer, those systems are expected to overflow or back up. As a result, sometimes storm runoff can enter buildings, creating the same types of damage that are caused by general conditions of flooding.

Existing school campuses should be evaluated to determine whether the drainage system is adequate and whether significant damage could occur if the design is overwhelmed by heavier runoff volumes. In particular, close attention should be given to the large paved areas that are often close to school buildings. All of the rain that falls on impervious paved surfaces runs off. If paved areas are sloped towards buildings, the likelihood of damage to the building is increased. How the landscaping is maintained and whether drainage paths, gutters, and storm drain grates are kept clear of debris will also affect the efficiency of the drainage system.

5.4.10 Emergency Measures

Emergency response to flooding is outside the scope of this manual. However, feasible emergency measures may provide some protection. The following description pertains only to emergency measures that have been used to reduce flood damage to older buildings that are already located in flood hazard areas. They may not provide protection to occupants and they can experience a high frequency of failure depending on human factors related to deployment. These measures do not achieve compliance with building and life-safety codes for new construction.

Emergency barriers are measures of last resort, and should be used only when a credible flood warning with adequate lead time is available and dependable. These measures have varying degrees of success, depending on the available manpower, skill required for installation, long-term maintenance of materials and equipment, suitability for site-specific flood conditions, and amount of advanced warning. Complete evacuation of protected buildings is appropriate, because emergency measures do not provide adequate protection for the safety of occupants.

Sandbag walls: Unless emergency placement is planned well in advance or under the direction of trained personnel, most sandbag barriers are not constructed in accordance with proper practices, leading to leakage and failures. Because of the intensive work effort and length of time required for protection even from relatively shallow water, sandbag walls are not a reliable protection measure. To be effective, sandbags and sand should be stockpiled and checked regularly to ensure that sandbags have not deteriorated. Sandbags have some other drawbacks, including high disposal costs and their tendency to absorb pollutants from contaminated floodwaters, which necessitates disposal as hazardous waste.

Water- or sand-filled barriers: A number of vendors make barriers that can be assembled with relative ease and filled with water or sand (see Figure 5-31). The barriers must be specifically sized for the site. Training and annual drills are important so that personnel know how to place and deploy the barriers. Proper storage, including cleaning after deployment, is necessary to protect the materials over long periods of time.

Panels for doors: For shallow and short-duration flooding, panels of sturdy material can be made to fit doorways to minimize the entry of floodwaters, although failure is common. Effectiveness is increased significantly if a flexible gasket or sealant is provided, and the mounting hardware is designed to apply even pressure. Personnel must know where the materials are stored and be trained in their deployment. A number of vendors make special doors for permanent installation and drop-in panels or barriers that are designed to be watertight.

Figure 5-31: Gravel-filled containers form a barrier to protect the University of Iowa (2008)

5.5 Schools as Emergency Shelters and Safe Rooms

Emergency managers regularly identify schools to serve as short-term and/or long-term community shelters. They are attractive sites for community shelters because they are designed for many people, with kitchen facilities, restroom and shower facilities, and open space gymnasiums, cafeterias, and wide corridors for cots and general gathering.

New schools that are intended to be used as emergency shelters are appropriately designed as essential or critical facilities that warrant a higher degree of protection than other schools. If located in or adjacent to flood hazard areas, it is appropriate to provide protection for the building and utility systems to at least the 0.2-percent-annual-chance (500-year) flood level or, at a minimum, 2 to 3 feet above the DFE.

Additional guidance on hazard-resistant shelters can be found in FEMA 361, *Design and Construction Guidance for Community Safe Rooms* (2008).

Starting with the 2009 edition of the IBC, the design and construction of community shelters are governed by both the provisions of the code and ICC 500, *ICC/NSSA Standard on the Design and Construction of Storm Shelters* (2008). In addition to requirements related to resistance to high winds, ICC 500 specifies that the minimum lowest floor elevation is the higher of four elevations: (1) the 0.2-percent-annual-chance flood (500-year) level; (2) the 1-percent-annual-chance flood level plus 2 feet (BFE + 2 feet); (3) 2 feet above the highest recorded flood elevation (if the area is not in a mapped SFHA); or (4) the maximum inundation elevation associated with a Category 5 hurricane event in an area subject to storm surge inundation.

The highest level of protection for sheltering is set forth in FEMA 361, *Design and Construction Guidance for Community Safe Rooms* (2008). The elevation criteria specified in FEMA 361 are equivalent to the criteria in the ICC 500 with one notable exception: to be designated a safe room, some special flood hazard areas must be avoided because the flood risk is too great. FEMA 361 guidance, which applies when the protection levels for safe rooms are desired, must be followed when Federal funding is being used to construct the safe room portion of a school. When designing an area of a school to provide the "near absolute" protection from tornadoes and hurricanes that are afforded by safe rooms, other criteria with respect to travel time to the safe room, the population to be protected, and the location of the safe room with respect to mapped flood hazard areas must all be considered. For additional information, please refer to the FEMA safe room policy MRR-2-09-1, *Hazard Mitigation Assistance for Safe Rooms* (2009c).

School districts and designers should also consider the following if schools are intended to be used as emergency shelters or safe rooms:

- Wastewater service must be functional during flooding conditions.
- Emergency power service must be provided.
- Dry-ground access is important even if flooding exceeds design levels.
- Mechanical and electrical equipment supporting the safe room or shelter must also be elevated as identified in FEMA 361 or ICC 500, respectively

5.6 Checklist for Vulnerability of Floodprone Sites and Schools

The Checklist for Building Vulnerability of Floodprone Schools (Table 5-3) is a tool that can be used to help assess site-specific flood hazards and building vulnerability. The checklist is useful during site selection, preliminary design of a new building, or when considering rehabilitation of an existing school. In addition to examining building design issues that affect vulnerability, the checklist also helps users to examine the functionality of the critical systems upon which most schools depend. The checklist is organized into separate sections, so that each section can be assigned to a subject expert for greater accuracy of the examination. The results should be integrated into a master vulnerability assessment to guide the design process and the choice of appropriate mitigation measures.

Table 5-3: Checklist for building vulnerability of floodprone schools

Vulnerability Sections	Guidance	Observations
Site Conditions		
Is the site located near a body of water (with or without a mapped flood hazard area)?	All bodies of water are subject to flooding, but not all have been designated as a floodplain on FIRMs.	
Is the site in a flood hazard area shown on the community's map (FIRM or other adopted map)? If so, what is the flood zone?	Flood hazard maps usually are available for review in local planning and permit offices. Electronic versions of the FIRMs may be available online at www.fema.gov. Paper maps may be ordered by calling (800) 358-9616.	
Is the site affected by a regulatory floodway?	Development in floodways, where floodwaters typically are faster and deeper, must be supported by engineering analyses that demonstrate no rise in flood levels.	
Is the site located in a storm surge inundation zone (or tsunami inundation area)?	In coastal communities, even sites at some distance inland from the shoreline may be exposed to extreme storm surge flooding. Storm surge maps may be available at State or local emergency management offices.	

Table 5-3: Checklist for building vulnerability of floodprone schools

Vulnerability Sections	Guidance	Observations
Site Conditions		
What is the DFE (or does an analysis have to be done to determine the DFE)? What is the minimum protection level required by regulatory authorities?	Reference the FIS for flood profiles and data tables. Site-specific analyses should be performed by qualified engineers. Check with regulatory authorities to determine the required level of protection.	
Does the FIS or other study have information about the 500-year flood hazard area? **Has FEMA issued post-disaster advisory flood elevations and maps?** **What are the expected depths of flooding at the site (determined using flood elevations and ground elevations)?**	If a major flood event has affected the community, FEMA may have issued new flood hazard information, especially if areas not shown on the FIRMs have been affected. Sometimes these maps are adopted and replace the FIRMs; sometimes the new data are advisory only.	
Has the site been affected by past flood events? What is the flood of record?	Records of actual flooding augment studies that predict flooding, especially if historic events resulted in deeper or more widespread flooding. Information may be available from local planning, emergency management, and public works agencies, or State agencies, the U.S. Army Corps of Engineers, or the Natural Resources Conservation Service. The flood of record is often a lower probability event (with higher flood elevations) than the 100-year flood.	
What is the expected velocity of floodwaters on the site?	Velocity is a factor in computing loads associated with hydrodynamic forces, including drag on building surfaces. Approximations of velocity may be interpolated from data in the FIS Floodway Data Table if the waterway was studied using detailed methods, application of approximation methods based on continuity, local observations and sources, or site-specific studies.	
Are waves expected to affect the site?	Waves can exert considerable dynamic forces on buildings and contribute to erosion and scour. Wind-driven waves occur in areas subject to coastal flooding and where unobstructed winds affect wide floodplains (large lakes and major rivers). Standing waves may occur in riverine floodplains where high velocities are present.	
Is there information on how quickly floodwaters may affect the site?	Warning time is a key factor in the safe and orderly evacuation of critical facilities. Certain protective measures may require adequate warning so that actions can be taken by skilled personnel.	
What is the expected duration of flooding?	Duration has bearing on the stability of earthen fills, access to a site and emergency response, and durability of materials that come into contact with water. Records of actual flooding are the best indicator of duration as most floodplain analyses do not examine duration.	

Table 5-3: Checklist for building vulnerability of floodprone schools

Vulnerability Sections	Guidance	Observations
Site Conditions		
Is there a history of flood-related debris problems or erosion on the site?	Site design should account for deposition of debris and sediment, as well as the potential for erosion-related movement of the shoreline or waterway. Buildings exposed to debris impact or undermining by scour and erosion should be designed to account for these conditions.	
Is the site within an area predicted to flood if a levee or floodwall fails or is overtopped?	Flood protection works may be distant from sites and not readily observable. Although a low probability event, failure or overtopping can cause unexpected and catastrophic damage because the protected lands are not regulated as flood hazard areas.	
Is the site in an area predicted to be inundated if an upstream dam were to fail?	The effects of an upstream dam failure are not shown on the FIRMs or most flood hazard maps prepared locally. Although dam failure generally is considered an unlikely event, the potential threat should be evaluated due to the catastrophic consequences. (Note: Owners of certain dams should have emergency action plans geared toward notification and evacuation of vulnerable populations and critical facilities.)	
Does the surrounding topography contribute to the flooding at the site? Is there a history of local surface drainage problems due to inadequate site drainage?	If areas with poor local drainage and frequent flooding cannot be avoided, filling, regrading, and installation of storm drainage facilities may be required.	
Given the nature of anticipated flooding and soils, is scour around and under the foundation likely?	Scour-prone sites should be avoided, in part due to likely long-term maintenance requirements. Flooding that is high velocity or accompanied by waves is more likely to cause scour, especially on fills, or where local soils are unconsolidated and subject to erosion.	
Has water from other sources entered the building (i.e., high groundwater, water main breaks, sewer backup, etc.)? Is there a history of water intrusion through floor slabs or well-floor connections? Are there underground utility systems or areaways that can contribute to basement flooding? Are there stormwater sewer manholes upslope of window areas or openings that allow local drainage to enter the basement/lower floor areas?	These questions pertain to existing facilities that may be impaired by water from sources other than the primary source of flooding. The entire building envelope, including below-grade areas, should be examined to identify potential water damage.	

Table 5-3: Checklist for building vulnerability of floodprone schools

Vulnerability Sections	Guidance	Observations
Site Conditions		
Is at least one access road to the site/ building passable during flood events?	Access is increasingly important as the duration of flooding increases. For the safety of occupants, most critical facilities should not be occupied during flood events.	
Are at-grade parking lots located in floodprone areas? **Are below-grade parking areas susceptible to flooding?**	Areas where vehicles could be affected should have signage to warn users, including bus drivers, of the risk. Emergency response plans should include notification of car owners.	
Architectural		
Are any critical building functions occupying space that is below the elevation of the 500-year flood or the DFE? **Can critical functions be relocated to upper levels that are above predicted flood elevations?** **If critical functions cannot be relocated, is floodproofing feasible?** **If critical functions must continue during a flood event, have power, supplies, and access issues been addressed?**	New critical facilities built in flood hazard areas should not have any functions occupying floodprone spaces (other than parking, building access, and limited storage). Existing facilities in floodplains should be examined carefully to identify the best options for protecting functionality and the structure itself.	
Have critical contents (files, computers, servers, equipment, research, and data) been located on levels of the facility above the flood elevations? **Are critical records maintained offsite?**	For existing facilities that are already located in flood hazard areas, the nature of the facility may require continued use of floodprone space. However, the potential for flooding should be recognized and steps taken to minimize loss of expensive equipment and irreplaceable data. If critical contents cannot be permanently located on higher floors, a flood response plan should take into account the time and attention needed to move such contents safely.	
Structural Systems		
What is the construction type and the foundation type and what is the load bearing capacity? **Has the foundation been designed to resist hydrostatic and hydrodynamic flood loads?**	If siting in a floodplain is unavoidable, new facilities are to be designed to account for all loads and load combinations, including flood loads.	

Table 5-3: Checklist for building vulnerability of floodprone schools

Vulnerability Sections	Guidance	Observations
Structural Systems		
If the building has below-grade areas (basements), are the lower floor slabs subject to cracking and uplift?	Below-grade spaces and their contents are most vulnerable to flooding and local drainage problems. Rapid pump out of below-grade spaces can unbalance forces if the surrounding soil is saturated, leading to structural failure. If below-grade spaces are intended to be dry floodproofed, the design must account for buoyant forces. Building spaces below the design flood level can be dry floodproofed, although it must be recognized that higher flood levels will overtop the protection measures and may result in severe damage. Dry floodproofing creates large unbalanced forces that can jeopardize walls and foundations that are not designed to resist the hydrostatic and hydrodynamic loads.	
Are any portions of the building below the DFE? **Has the building been damaged in previous floods?**	For existing buildings, it is important to determine which portions are vulnerable in order to evaluate floodproofing options. If flood depths are expected to exceed 2 or 3 feet, dry floodproofing may not be feasible. Alternatives include modifying the use of floodprone areas.	
If the building is elevated on a crawlspace or on an open foundation, are there any enclosed areas?	New buildings may have enclosures below the flood elevation, provided the use of the enclosures is limited (crawlspace, parking, building access, and limited storage). In addition, the enclosures must have flood openings to automatically allow for inflow and outflow of floodwaters to minimize differential hydrostatic pressure. Existing buildings that are elevated and have enclosures below the flood elevation can be retrofit with flood openings.	
For an existing building with high-value uses below the flood elevation, is the building suitable for elevation-in-place, or can it be relocated to higher ground?	Elevating a building provides better protection than dry floodproofing. Depending on the type and soundness of the foundation, even large buildings can be elevated on a new foundation or moved to a site outside of the floodplain.	
Building Envelope		
Are there existing floodproofing measures in place below the expected flood elevation? What is the nature of these measures and what condition are they in? Is there an annual inspection and maintenance plan? **Is there an "action plan" to implement floodproofing measures when flooding is predicted? Do the building operators/ occupants know what to do when a flood warning is issued?**	Floodproofing measures are only as good as the design and their condition, especially if many years have passed since initial installation. Floodproofing measures that require human intervention are entirely dependent on the adequacy of advance warning, and the availability and ability of personnel to properly install the measures.	

Table 5-3: Checklist for building vulnerability of floodprone schools

Vulnerability Sections	Guidance	Observations
Building Envelope		
For existing buildings, what types of openings penetrate the building envelope below the 500-year flood elevation or the DFE (doors, windows, cracks, vent openings, plumbing fixtures, floor drains, etc.)?	For dry floodproofing to be effective, every opening must be identified and measures taken to permanently seal or to prepare special barriers to resist infiltration. Sewage backflow can enter through unprotected plumbing fixtures.	
Are flood-resistant materials used for structural and nonstructural components and finishes below the 500-year elevation or the DFE?	Flood-resistant materials are capable of withstanding direct and prolonged contact with floodwaters without sustaining damage that requires more than cosmetic repair. Contact is considered to be prolonged if it is 72 hours or longer in freshwater flooding areas, or 12 hours or longer in areas subject to coastal flooding.	
Utility Systems		
Is the potable water supply for the facility protected from flooding? If served by a well, is the wellhead protected?	Operators of critical facilities that depend on fresh water for continued functionality should learn about the vulnerability of the local water supply system, and the system's plans for recovery of service in the event of a flood.	
Is the wastewater service for the building protected from flooding? **Are any manholes below the DFE? Is infiltration of floodwaters into sewer lines a problem? If the site is served by an onsite system that is located in a floodprone area, have backflow valves been installed?**	Most waste lines exit buildings at the lowest elevation. Even buildings that are outside of the floodplain can be affected by sewage backups during floods.	
Are there any aboveground or underground tanks on the site in flood hazard areas? Are they installed and anchored to resist flotation during the design flood? Are tank openings and vents elevated above the 500-year elevation or the DFE, or otherwise protected to prevent entry of floodwater or exit of product during a flood event?	Dislodged tanks become floating debris that pose special hazards during recovery. Lost product causes environmental damage. Functionality may be impaired if tanks for heating fuel, propane, or fuel for emergency generators are lost or damaged.	
Mechanical Systems		
Are air handlers, HVAC systems, ductwork, and other mechanical equipment and systems located above the 500-year elevation or the DFE? Are the vents and inlets located above flood level, or sealed to prevent entry of floodwater?	In existing buildings, utility equipment that is critical for functionality should be relocated to higher floors or into elevated additions.	
Plumbing and Gas Systems		
Are plumbing fixtures and gas-fired equipment (meters, pilot-light devices/ burners, etc.) located above the 500-year elevation or the DFE?	In existing buildings, utility equipment that is critical for functionality should be relocated to higher floors or into elevated additions.	

Table 5-3: Checklist for building vulnerability of floodprone schools

Vulnerability Sections	Guidance	Observations
Plumbing and Gas Systems		
Is plumbing and gas piping that extends below flood levels installed to minimize damage?	Piping that is exposed could be impacted by debris.	
Electrical Systems		
Are electrical systems, including backup power generators, panels, and primary service equipment, located above the 500-year elevation or the DFE? **Are pieces of electrical stand-by equipment and generators equipped with circuits to turn off power?** **Are the switches and wiring required for safety (minimal lighting, door openers) located below the flood level designed for use in damp locations?**	In existing buildings, utility equipment that is critical for functionality should be relocated to higher floors or into elevated additions.	
Fire Alarm Systems		
Is the fire alarm system located above the 500-year elevation or the DFE?	In existing buildings, utility equipment that is critical for functionality should be relocated to higher floors or into elevated additions.	
Communications and IT Systems		
Are the communication/IT systems located above the 500-year elevation or the DFE?		

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Organizations and Agencies

Federal Emergency Management Agency: 10 regional offices (www.fema.gov) can be contacted for advice and guidance on NFIP mapping and regulations.

NFIP State Coordinating offices help local governments to meet their floodplain management obligations and may provide technical advice to others; the offices are listed by the Association of State Floodplain Managers, Inc., (www.floods.org/stcoor.htm).

State departments of education or agencies that coordinate State funding and guidelines for schools may have State-specific requirements.

U.S. Army Corps of Engineers. District offices offer Flood Plain Management Services (www.nap.usace.army.mil/cenap-op/regulatory/districts.html).

5.8 Glossary of Flood Protection Terms

Advisory Base Flood Elevation. Flood elevation that is determined by a reassessment of base flood elevations conducted after significant flood events.

Base flood. The flood having a 1-percent chance of being equaled or exceeded in any given yea, commonly referred to as the “100-year flood.” The base flood is the national standard used by the NFIP and all Federal agencies for the purpose of regulating development.

Base flood elevation (BFE). The height of the base (1-percent or 100-year) flood in relation to a specified datum, usually the National Geodetic Vertical Datum of 1929 or the North American Vertical Datum of 1988.

Coastal High Hazard Area. An area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high velocity wave action from storms. Coastal high hazard areas also are referred to as “V Zones” and are designated on Flood Insurance Rate Maps (FIRMs) as zones VE or V1-30.

Design flood. The greater of the following two flood events. (1) the base flood, affecting those areas identified as special flood hazard areas on a community’s FIRM; or (2) the flood corresponding to the area designated as a flood hazard area on a community’s flood hazard map or otherwise legally designated.

Design flood elevation (DFE). The elevation of the design flood, including wave height, relative to the datum specified on a community’s flood hazard map.

Dry floodproofing. Any combination of structural and nonstructural additions, changes, or adjustments to structures, or combinations thereof that eliminate or reduce the potential for flood damage by resisting flood loads, sealing walls, and closing openings to keep water from entering a building.

Federal Emergency Management Agency (FEMA). The Federal agency that, among other functions, administers the National Flood Insurance Program (NFIP).

Flood Insurance Rate Map (FIRM). The official map of a community on which FEMA has delineated both special flood hazard areas (SFHA) and flood zones. Some FIRMs include base flood elevations, 500-year floodplain boundaries, and regulatory floodway boundaries.

Flood Insurance Study (FIS). An engineering study performed by FEMA to identify flood hazard areas, flood insurance risk zones, and other flood data in a community; used in the development of the FIRM.

Flood profile. A graph of computed flood elevations at points located along a riverine waterway. Flood profiles typically are available for waterways that have BFEs shown on FIRMs, and are found in FISs.

Flood zone. A designation for areas that are shown on Flood Insurance Rate Maps.

Floodplain. Any land area, including a watercourse and the land adjacent to it, that is susceptible to being inundated by water from any source.

Floodplain management regulations. Zoning ordinances, subdivision regulations, building codes, health regulations, or special-purpose ordinances that set flood-resistant standards for construction and development.

Floodway. The channel of a river or other watercouse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation by more than a designated height.

Freeboard. A factor of safety, usually expressed in feet above a flood level, for purposes of floodplain management. Freeboard also compensates for unknown factors that could contribute to flood heights greater than the height calculated for a selected frequency flood and floodway conditions, such as wave action, blockage of bridge openings, and the effects of upland urbanization. A freeboard of from 1 to 3 feet is often applied to critical facilities.

Human intervention. Actions that must be taken by one or more persons in order for a building to be floodproofed prior to the onset of flooding.

Hydrodynamic load. The load imposed by water flowing against and around an object or structure, including the impact of debris and waves.

Hydrostatic load. The load (pressure) imposed on an object or structure by a standing or slowly moving mass of water; the deeper the water, the greater the hydrostatic load or pressure.

Limit of Moderate Wave Action. The inland limit of the area affected by waves greater than 1.5 feet.

Lowest floor. The lowest floor of the lowest enclosed area (including a basement) of a building. An unfinished or flood-resistant enclosure, usable solely for parking of vehicles, building access, or storage, in an area other than a basement, is not considered a building's lowest floor, provided that the enclosure is compliant with flood-resistant requirements.

National Flood Insurance Program (NFIP). The Federal program, administered by FEMA, that identifies flood-prone areas nationwide and makes flood insurance available for properties in communities that participate in the program.

Scour. Removal of soil or fill material from the channel cross-section or land surface by the flow of floodwaters.

Sheetflow. Rainfall-runoff that flows over relatively flat land without concentrating into streams or channels.

Special flood hazard area. An area delineated on a FIRM as being subject to inundation by the base flood and designated as Zone A, AE, A1–A30, AR, AO, AH, A99, V, VE, or V1–V30.

Stillwater elevation. The elevation that the surface of coastal floodwaters would assume in the absence of waves, referenced to a datum.

Substantial damage. Damage of any origin sustained by a structure, whereby the cost of restoring the structure to its pre-damage condition equals or exceeds 50 percent of the market value of the structure before the damage occurred (or smaller percentage if established by the authority having jurisdiction). Structures that are determined to be substantially damaged are considered to be substantial improvements, regardless of the actual repair work performed.

Substantial improvement. Any reconstruction, rehabilitation, addition, or other improvement of a structure, the cost of which equals or exceeds 50 percent of the market value of the structure (or smaller percentage if established by the authority having jurisdiction) before the start of the improvement.

Wave runup. Rush of wave water running up a slope or structure.

Wet floodproofing. Permanent or contingent measures applied to a building and/or its contents to minimize flood damage by modifying interior finishes, removing damageable items from lower areas, and allowing water into the building.